NORTH CONCHO RIVER WATERSHED RESTORATION

HYDROLOGIC RESPONSE MONITORING & RESEARCH

2000 - 2006

PREPARED BY

UPPER COLORADO RIVER AUTHORITY

TEXAS INSTITUTE FOR APPLIED ENVIRONMENTAL RESEARCH

AT TARLETON STATE UNIVERSITY

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EXECUTIVE SUMMARY

Since 2000, the Upper Colorado River Authority, which is based in San Angelo, Texas, has been involved in a response monitoring effort within the North Concho River watershed. This approximate 905,000 acre watershed has been the subject of a $17.8 million hydrologic restoration program dedicated to the removal or treatment of phreatophytes (mostly honey mesquite and juniper) to enhance watershed yields. The program began with the publication of a 1998 feasibility study presented to the Texas Legislature. Historical hydrological data reported in the study indicated that since 1960 the watershed has undergone a significant change in hydrologic characteristics including a significant decrease in the production of surface water runoff to O.C. Fisher Reservoir. It was also within this time period that the watershed's brush condition matured to its pre program condition. In the feasibility study, approximately 435,000 acres within the watershed were identified for brush treatment. To date, approximately 302,000 acres has been treated.

The response monitoring effort has focused on measuring various hydrologic parameters such as regional groundwater elevations, measurements of base flows, the number, frequency, duration and distribution of flood flows, in–stream losses, and flood flow hydrograph characteristics. Hydrologic research has also occurred during the period and has generally focused on the collection of experimental hydrologic data in paired watershed situations (treated sites vs. untreated sites).

Even though the watershed response monitoring has occurred primarily under record drought conditions and the implementation of brush control is phased biennially, the data collected to date indicates a gradual shift in hydrologic characteristics to the pre-brush condition. Ground water levels have continued to trend in an upward fashion and numerous previously dry springs and seeps have begun to be active again. Base flows on previously dry or intermittent tributaries have become perennial and base flows on the North Concho River at several locations have steadily increased with time. For the first time in many decades, the North Concho River experienced perennial base flows throughout the entire stream reach. The fact that stream channel losses during storm events have declined significantly since 2000 and the results of a comparative analysis of flood flow hydrographs from similar storm events indicate the onset of a shift in the river's hydrologic behavior to the pre-brush condition. Stream flow monitoring conducted on two almost identical 25,000 acres sub-watersheds (East and West

Forks of Grape Creek) indicates that, on the treated watersheds, perennial base flows have been re-established and produce significant water yield on an annual basis. The untreated sub-watersheds have produced virtually no water yield during the same period. The water produced from the treated watersheds closely matches the quantities predicted not only by the SWAT model, which was used in the feasibility study, but also by the data collected in the ongoing evapotranspiration (ET) hydrologic research project.

INTRODUCTION

On September 1, 1999, the Upper Colorado River Authority (UCRA) was awarded a contract from the Texas State Soil And Water Conservation Board (TSSWCB) to provide services resulting in effective monitoring and assessment of an on-going brush control program on the North Concho River watershed. This award and funding for the brush removal project was provided by the Texas Legislature in response to recommendations contained in the *North Concho River Watershed Brush Control Planning, Assessment and Feasibility Study* prepared in 1998 by the UCRA, the Texas A&M Agricultural Research program and TSSWCB. The purpose of the feasibility study was to determine the potential hydrologic benefits that might be gained through implementation of a brush removal project on the watershed. To measure the effectiveness of the brush control program, the UCRA was tasked with the development and implementation of a multi-task and multi-year hydrologic response monitoring program that included paired watershed research studies, ground water monitoring and surface water flow monitoring. In the subsequent program years, and as the watershed restoration progressed, several other study elements were added, including special studies on Chalk Creek and Grape Creek. Since the initial contract, the watershed response monitoring has taken several forms due to funding methods, but data collections on the watershed have been generally consistent to date. Since 1999, the response monitoring and research on the watershed has been funded through several agencies including the UCRA, Texas Water Development Board, TSSWCB, and the United States Environmental Protection Agency (TSSWCB 319 program). Currently, the program is primarily administered by the UCRA with assistance from the Texas Institute of Applied Environmental Research at Tarleton University. In addition, assistance is obtained from the Sterling County Underground Water Conservation District and the Texas Water Development Board. A project advisory committee made up of Concho River Basin stakeholders also assist UCRA staff in project oversight and planning.

The long term comprehensive monitoring of the North Concho River watershed including both the surface and ground water resources of the watershed is extremely valuable, especially since this is the first program of it's type in the state. The data collected from these on-going studies and the experience derived from implementation of the program will likely effect brush control strategies and programs for decades.

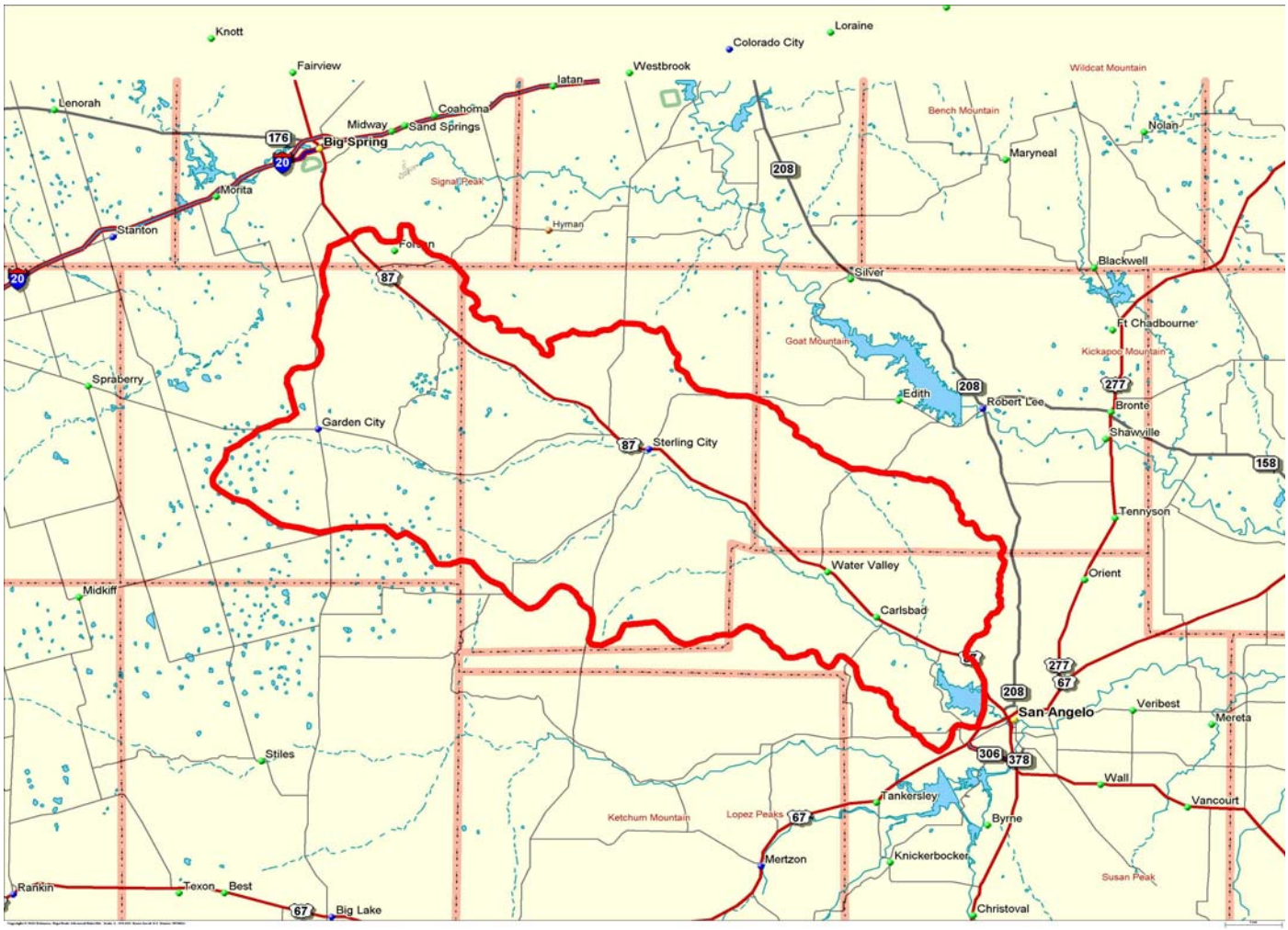
At the outset of the program, the Texas Legislature, TSSWCB and UCRA projected a ten year monitoring period. At the end of the 2006 FY, the program will have been in operation for seven years. The paired watershed and other research studies are entering the sixth year of on-line status and are currently providing research data that has not previously existed in the scientific literature. This information is considered to be of critical importance to the future of brush control efforts and will likely have a considerable impact on every phase of the program from modeling to implementation. The carefully controlled monitoring of the water budget within these sites and the brush removal from the target sites offer opportunities for future research into a variety of other related issues that will be difficult to duplicate elsewhere.

The purpose of this report is to make available the data and information collected to date in the response monitoring and research effort. This data and preliminary conclusions will assist various state and local agency staff and lawmakers in planning future restoration projects and in making critical decisions regarding existing and planned projects. In addition, it is hoped that the data and observations presented herein will provide the impetus to develop new, rational research efforts into the potential water production and water conservation benefits associated with brush removal (particularly the control of honey mesquite within watersheds similar to the North Concho River in hydrologic and geologic characteristics).

DESCRIPTION OF THE WATERSHED

The North Concho river watershed is located in West Central Texas within Tom Green, Sterling, Glasscock and Coke counties. A location map of the North Concho Watershed follows. West Central Texas has a sub-tropical climate; dry in winter, and warm and humid in summer. Average annual rainfall varies from approximately 20 inches in Tom Green County to approximately 16 inches in Glasscock County. Most of the precipitation is received from thunderstorms

during May through October. Thunderstorm rainfall in West Texas is extremely variable. Large differences in rainfall amounts exist from year to year within small geographical areas. While the North Concho river watershed originates in Southern Howard County no significant water course or perennial stream flows are encountered until the stream enters northwestern Sterling County. The stream terminates within the city of San Angelo as the north and south fork of the Concho River converge to become what is commonly called the "Main" Concho or simply, the Concho River. O.C. Fisher Reservoir was constructed in the early 1950's immediately above San Angelo for flood protection and storage for a primary water supply. Since construction, O.C. Fisher Reservoir has performed below expectations as a water supply.



In its fifty year history, municipal water has been available from the reservoir for brief and sporadic periods of time. The watershed is utilized primarily for ranch pasture with the propagation of cattle and sheep as the major land use. Some cultivation exists, but with the exception of portions in Glasscock County and minor areas in Tom Green County, farming consists of small grain production in support of livestock operations. Except for oil and gas production, no major industries are located in the watershed.

The assumption for this report is that the watershed terminates at O.C. Fisher Reservoir. The City of San Angelo, with a population of 100,000, is the largest metropolitan area located within the watershed. Other communities in the watershed include Grape Creek, Carlsbad, Water Valley, Sterling City and Garden City. There is substantial rural subdivision development in the lower portion of the watershed, primarily in Tom Green County.

Elevations within the watershed range from near 2700 ft. MSL on the western side to near 1800 Ft. MSL near San Angelo. The area is generally comprised of broad valleys near the rivers and tributaries which consist primarily of geologically recent terrace deposits flanked by hills, buttes and plateaus of Edwards Limestone. Much of the hills and plateaus are covered with juniper, live oaks and small brush, while the valleys are typified by dense mesquite thickets.

- SWAT modeling looked at a 904,926 acre watershed, 37,283 acres was non-productive (1998 Feasibility Study).
- The SWAT model identified (15) sub-basins (most are tributary systems).
- In 1998 432,485 acres of brush was identified as eligible for treatment under the State program.
- Topographically, the watershed consists of broad valleys near the river and tributary systems primarily made up of geologically recent terrace deposits flanked by hills, buttes and plateaus of Edwards Limestone.
- Characteristically, brush distribution within the watershed consists of hills and plateaus covered with juniper and valleys covered by dense mesquite thickets.

Brush Program Status:

- The TSSWCB entered into brush treatment cost share contracts in the fall of 2000.
- Approximately 302,000 acres of brush have been treated at a cost to the state of nearly $13.7 million with the landowners share equaling close to $4.1 million.

Watershed Ecological Changes:

- From historic accounts beginning in the mid 19th century, there has been a dramatic ecologic shift from a grassland prairie to complete infestation of the watershed by juniper and mesquite.
- This shift to the present vegetative condition was generally complete by the mid 20th Century.
- Based on historical accounts and hydrologic records, a “normal” condition of perennial stream flows and the existence of significant aquatic habitats throughout the watershed was enjoyed by the main stem and major tributaries. This changed gradually during the first half of the 20th century to its present condition. This change seems to have been complete following the record drought of the 1950’s.

Watershed Climate:

- Average annual rainfall for the watershed ranges from approximately 16 inches per year on the western edge to approximately 20 inches in Tom Green County.
- Regional rainfall records do not indicate any significant long term changes in annual precipitation.
- Most of the annual rainfall occurs during the spring and fall months in the form of thunderstorms.

Water Consumption within the Watershed:

- Categories of direct water consumption, related to human activities, include organized domestic use, individual domestic use, crop irrigation and livestock uses.

- Direct water consumption within the watershed is almost totally from groundwater sources.
- The total annual direct water consumption within the watershed is currently less than 5,000 acre feet or 0.06316 inches per year per acre.
- Historically, total direct water consumption has steadily declined from a peak period in the 1930's and 1940's.

Watershed Hydrology:

- Based on TWDB water well data, there appears to have been a significant decline in static water levels in water wells within the watershed from the 1940's to the 1960's.
- Based on records obtained at the USGS station near Carlsbad from 1925 through 1959 the following hydrologic characteristics were calculated:

  Average annual stream flow was 38,617 acre feet per year.
  Rainfall runoff events occurred 7.31 times per year.
  Average runoff event produced 4,560 acre feet.
  Runoff events occurred in every month, typically with the most activity occurring in May and the least in December.
  The average annual mean flow was 48 CFS.
  The base flows could be expected to be greater than 2.0 CFS 60.5% of the year.
  Base flows greater than 30 CFS could be expected 20 days per year.
- Based on records obtained at the USGS station near Carlsbad from 1960 through 1996, the following hydrologic characteristics were calculated:

  Average annual stream flow was 8,358 acre feet per year.
  Rainfall runoff events occurred 2.89 times per year.
  Average runoff events produced 3,145 acre feet.
  No runoff events occurred during summer months.
  The average annual mean flow was 30 CFS
  The base flow could be expected to be greater that 2.0 CFS 36.3 % of the time.
  Base flows greater than 30 CFS could be expected 7.3 days per year.
- "Typical" storm water hydrographs from pre and post 1960 storm events contain significantly different characteristics.

FEASIBILITY STUDY

As stated previously, a study was published by the UCRA in 1998 entitled, *"North Concho River Watershed Brush Control: Planning, Assessment and Feasibility*". The study was funded by the UCRA, the TWDB and the Texas Clean Rivers Program, through the Texas Commission on Environmental Quality (TCEQ). Participants in the study included the UCRA, Texas A&M Agricultural Research Station (San Angelo), Blackland Research Facility (Temple), TSSWCB, USDA Natural Resources Conservation Service and others. The study also included considerable input from watershed landowners and the general public. The purpose of the study was to define ecological changes in the watershed over time and determine if those changes altered the hydrologic conditions. The study determined (through modeling) that removal of brush from the watershed could produce hydrologic benefits, and quantitatively estimated those benefits. The study also provided cost/benefit analysis that estimated economic benefits to the landowners and the state. Recommendations to the cost share program were eventually developed by the TSSWCB. The public and landowner participation in the study also proved to be extremely valuable to the resulting brush removal program. As a result, acceptable and workable program requirements were developed and implemented.

The following excerpts are discussions taken from the feasibility study as related to several pertinent topics. They have been included to provide the reader with insight into the content and organization of the feasibility study.

The Effects of Brush Control on Water Yield

"Prior to simulation of stream flow in the North Concho River, a Geographic Information System (GIS) was developed to characterize the area and provide inputs for the simulation model. Data layers in the GIS included soils, topography, climate and vegetation type. The present amount of land in different vegetation types was determined using satellite imagery that was ground truthed for accuracy. The vegetation types and amounts of acreage of primary interest to this study were heavy cedar - 110,508 acres; heavy mesquite - 155,896 acres; moderate mesquite - 92, 735 acres; and light brush - 73,346 acres. Thus a total of 432,485 acres or 45% of the watershed should be considered for some form of a brush control program to restore stream flow in this river."

"The agreement between actual and simulated flow was considered accurate enough to use the model to estimate the effect of various brush management scenarios on water yield. For the simulation of different brush management

scenarios, it was assumed that the underground aquifer was replenished to pre - 1962 levels. Thus the simulated increases would not be expected to occur until some future time following the initiation of a watershed scale brush control program when the underground aquifers would be replenished."

"Greatest reduction in evapotranspiration resulted from the removal of heavy cedar. However, this did not yield the greatest increase in flow to the river because cedar is located further from the stream bed. Following recharge of the shallow aquifer, reduction of brush cover on all eligible lands to a 5% canopy which would increase the North Concho River flow at Carlsbad by 33,515 acre feet above the current discharge rate. This represents over a five-fold increase in stream flow and in more water annually than the City of San Angelo uses."

Economic Analysis

"Economic analysis of the different brush control alternatives was based on estimating control costs of the different options and comparing them to the rancher estimated benefits of brush control."

"The state cost share is estimated as the difference between the present value of the total cost per acre of the control program and the present value of the rancher benefits. Present values of the state cost share per acre of the brush control in the southeast range from $56 for control of heavy cedar with tree dozing to $9 for control of heavy cedar with two way chaining and burning. In the northwest, the state cost share ranges from $58 to $11 for the same control practices. Present value of state cost share for control of heavy mesquite was estimated at $39 per acre.

Based on these analyses, $12 million in state funding is required for state cost share of brush control on all of the qualifying acreage in the watershed. Of this total $6 million should be appropriated in 2000-2001 biennium and the remaining 6 million over the following three bienniums."

Implementation

"The North Concho Brush Management Program should be administered at the state level through the Texas State Soil and Water Conservation Board under the Texas Brush Control Plan, developed in accordance with Chapter 203 of the Agricultural Code. This code should be amended to allow greater flexibility in cost share to accomodate the North Concho as well as other projects to come throughout Texas. Funds for implementation should be deposited in the State

Brush Control Fund. Cost share funds will be administered at the local level by those Soil and Water Conservation Districts participating in the program based on allocations from TSSWCB. The Districts should contract with individual landowners for developing and implementing individual brush control plans. However, TSWCB and Texas A & M should initiate quality control measures to insure proper herbicide mix and applications."

PROGRAM IMPLEMENTATION

The feasibility study was distributed not only to state legislators, but also to stakeholders and interested entities located throughout Texas. Initial implementation funds for the North Concho River Pilot Brush Control Project were appropriated in 1999 during the 76th Texas legislative session. Additional funds were appropriated during the 77th and 78th legislative sessions in 2001 and 2003. As of this writing, a total of 314 landowner brush treatment contracts have been entered into with the TSSWCB. Since the program's inception, a total of 302,074 acres have been treated in the North Concho River watershed, with an additional 35,211 contracted acres remaining to be treated. A breakdown of the total acres treated by fiscal year follows:

FY2000- none
FY 2001- 75,000 acres
FY 2002 – 155,000 acres
FY 2003 – 207,537 acres
FY 2004 – 295,510 acres
FY2005 – 299,361 acres
Present – 302,074 acres

Thus far, the total cost has been $13.7 million to the state and $4.1 million to landowners. Program cost share rules call for the state to pay 70% of the cost of mechanical treatment (up to a maximum of $70 per acre) and 70% of the cost of aerial treatment for mesquite (up to a maximum of $27 per acre). These maximum amounts include a financial incentive for the deferment of grazing. Prior to the issuance of contracts or the treatment of brush, Soil and Water Conservation Planners or TSSWCB staff wrote a ten year Conservation Plan which addressed brush concerns, follow-up treatments, prescribed grazing and upland wildlife habitat management. Contracts were then written by a Soil And Water Conservation Planner or TSSWCB staff member. Included within a contract, are maps that delineate and quantify the areas to be treated, the method(s) of treatment and the treatment costs. After the work was performed,

the Soil and Water Conservation Planner or TSSWCB staff member certified that the work performed by the landowner complied with the contractual obligations. The certification process was then concluded with the attachment to the file of a map of the actual areas treated and the actual costs of the treatment(s).

Although legislation for a brush control cost share program had existed for several years, until the North Concho River Pilot Project came to fruition, no project of this type had ever been attempted in Texas. The rules governing the administration and implementation of the program had to be developed by the TSSWCB, without the benefit of any previous experience regarding such programs. Similarly, there existed no familiarity or understanding by landowners with the governing rules of such a program. As a result, there existed an initial reluctance by landowners to elect to participate. In an effort to alleviate this situation, several well-publicized public meetings were held to not only explain the workings of program, but also to elicit stakeholder input. As a result, some of the rules were revised to encourage landowner participation. Ultimately, when landowners began to understand and have confidence in the program, the sign-up rate rapidly increased and a waiting list ensued. Contracts were issued on a first come basis and no attempt was made to prioritize areas to be treated.

These procedures and rationale were modified with the initiation of the Twin Buttes Reservoir watershed brush treatment program a few years later. In that program, an attempt was made to prioritize and treat the most productive sub-basins first, and contracts were entered into only with landowners whose land was located within the high priority sub-basins. In retrospect, from a hydrologic standpoint, this rationale provides for a much superior program. The fact that the North Concho program did not utilize this rationale was likely due to an intent by the planners to treat all of the identified brush areas located within the watershed. However, this intent has not been realized and likely cannot be realized, given the nature of a voluntary cost share program conducted on privately owned lands. The final outcome of the approach used in the North Concho River Pilot Project is that, nearing completion of the project, large areas of mesquite in high priority areas have not been treated.

HYDROLOGIC RESPONSE MONITORING

Rationale and Design

The UCRA is conducting a hydrologic response monitoring program In conjunction with the pilot North Concho Watershed Brush Control Project. Given

the size of the watershed and the many variables involved, it is impossible to design a monitoring program capable of providing an all-inclusive accounting of water inputs and outputs from which to derive an accurate water balance. The rationale and design of the monitoring program was therefore necessarily based on measuring and comparatively analyzing certain parameters identified and reported in the feasibility study.

Hydrological changes that occurred concomitant with the proliferation of noxious brush were documented in the North Concho feasibility study. As part of that study, a comprehensive analysis of existing hydrological data was performed. The results of that analysis included the identification of various pre-brush and post-brush hydrologically characteristic “norms” for the watershed. These watershed “norms” include the frequency, annual distribution, duration and yield of storm water events, annual base flows and groundwater elevations. The monitoring program seeks to measure these (and similar parameters) and analyze the data to identify and document any indications of a return of watershed hydrologic characteristics from the post-brush condition existent at the inception of the brush control project, to the pre-brush conditions existent prior to 1960. The data collected and analyses performed to date are discussed in the following portions of this report.

Prior to the inception of this monitoring project, two (2) USGS maintained stream flow gauging stations existed on the North Concho River. These stations are the North Concho River near Carlsbad Station, station number 08134000, with flow records available from 1925 to present, and the North Concho River at Sterling City Station, station number 08133500, with flow records available from 1940 to 1984, (at which time the station’s measuring configuration was changed from a total flow to a flood flow station). To enhance coverage, two additional USGS stream flow stations were installed on the river at critical locations and have since operated continuously. The North Concho River above Sterling City Station, station number 08133250, was installed near the source springs of the river on the “U” Ranch north of Sterling City. The North Concho River near Grape Creek Station, station number 08134250, was installed immediately upstream of O.C. Fisher Reservoir.

In the second program biennium, two additional USGS gauging stations were installed on tributaries of the North Concho River. The Grape Creek near Grape Creek Station, station number 08134230, was installed near the mouth of Grape Creek and the Chalk Creek near Water Valley Station, station number 08133900,

was installed near the mouth of Chalk Creek. These locations were selected for the installation of gauges because of the significant amount of brush removed within the Chalk Creek and Grape Creek sub-basins.

Additional flow monitoring sites were selected by the UCRA at which to manually measure flows on a periodic basis. Data collected from these sites, used in conjunction with the USGS data, provide a good “snapshot” of the entire stream-reach flow characteristics of the North Concho River at regular points in time. In addition to the characterization of base flows, these data are also used to evaluate various storm event runoff characteristics including the analysis of channel transmission losses.

Existing water wells located throughout the watershed are utilized by the UCRA to periodically measure static ground water elevations. These data are used to evaluate water table fluctuations and their effects on surface water flows.

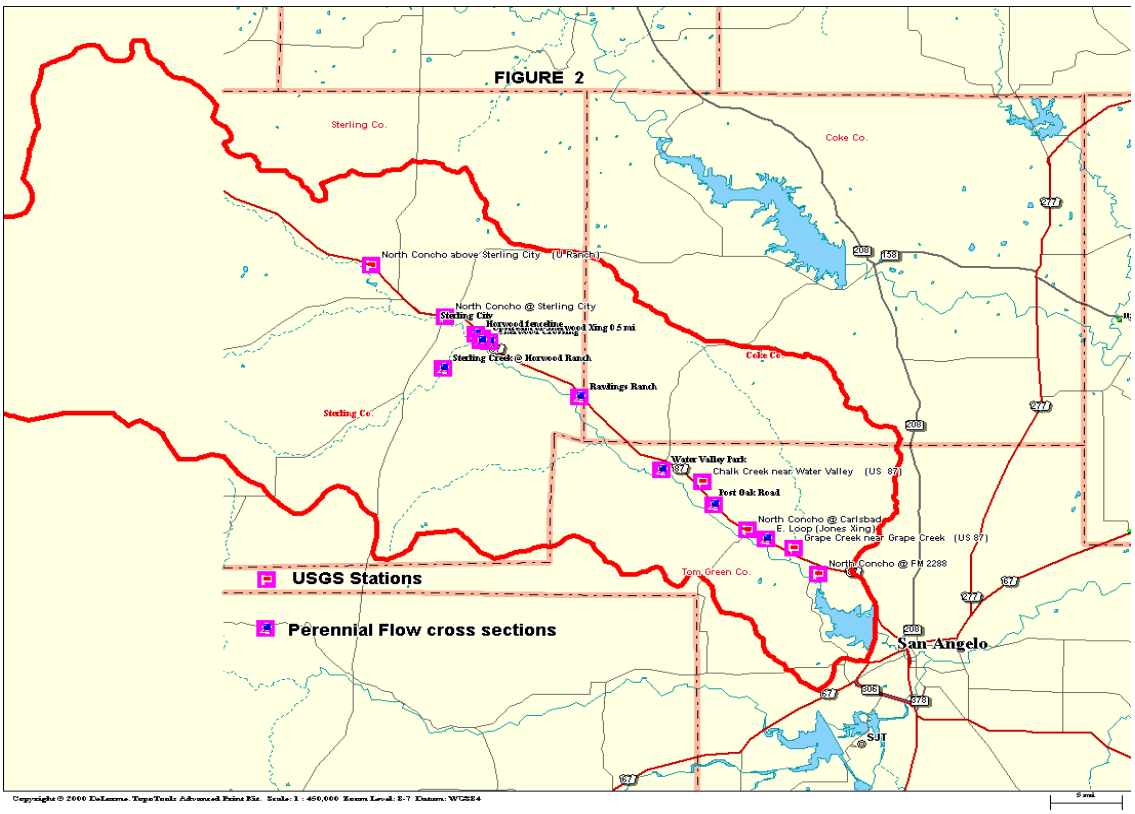
Surface Water Observations

The North Concho River is regaining perennial characteristics. In 2005, the North Concho River began to produce sustained base flows from the headwaters all the way to O.C. Fisher Lake. As of May 2006, approximately forty miles of perennial flow aquatic habitat now exists within the watershed that did not exist in 2000. This habitat presently exists along Sterling Creek, Grape Creek (East Fork) and the normally dry portions of the North Concho River.

Typically, over the last several years of monitoring, the river has had dry segments scattered along its reach. Some of the most notable dry areas were above Sterling City and also between Carlsbad and Grape Creek where the river just disappeared underground. This phenomenon is attributed to depleted alluvial aquifers. Through time, these alluvial deposits have become saturated and now the river runs throughout its reach. Since the North Concho is again transporting water, rainfall events that generate runoff deliver water to O.C. Fisher Lake.

The UCRA currently monitors 10 surface water sites along the North Concho River and 1 site on Sterling Creek, just above the confluence of the North Concho. These stations are visited on at least a quarterly basis and flows are measured. The data accumulated since 2000 reflects a gradual gaining trend in base flows. Even more impressive are the perennial base flows that have continued “non-stop” over the last 18 months on both the North Concho River

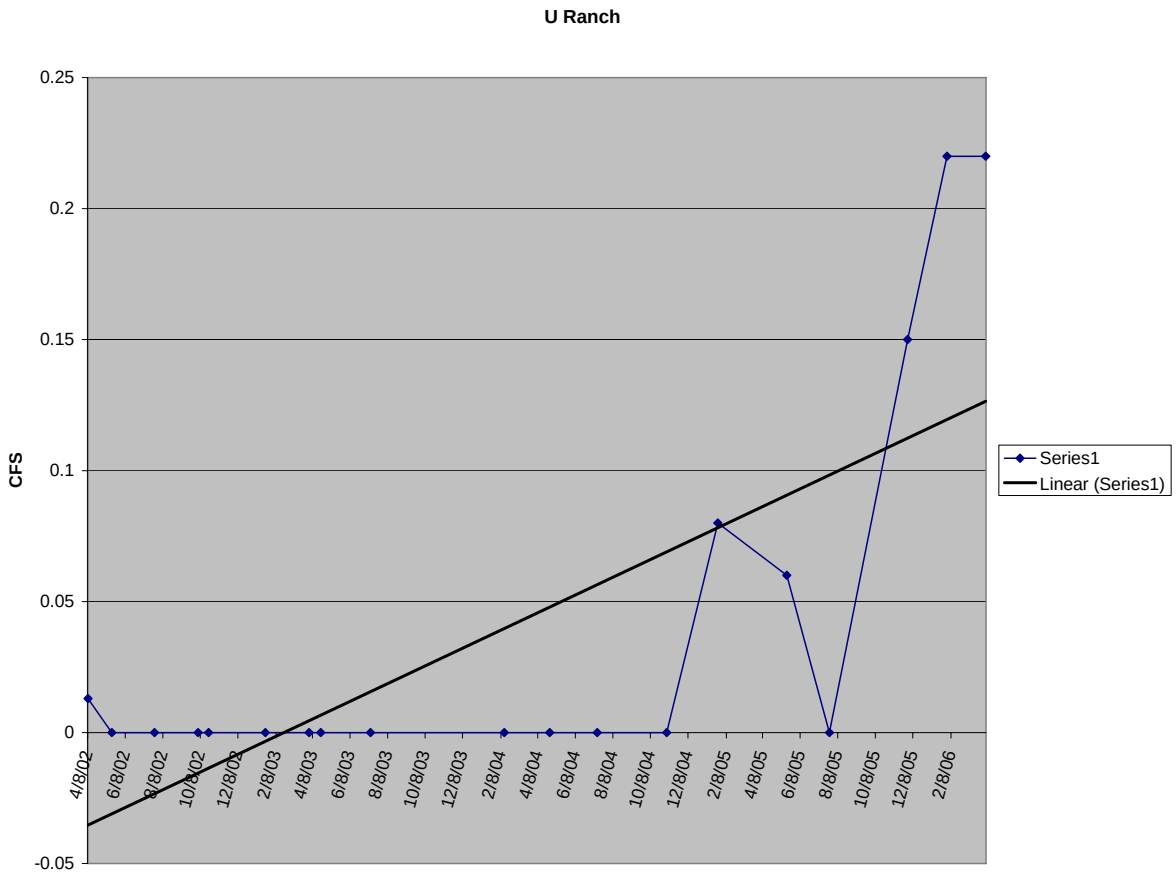
and Sterling Creek. During this same period, the region has experienced slightly below average precipitation, according to National Weather Service data recorded in San Angelo. Map of sites (fig. 2) as well as flow data are shown below.

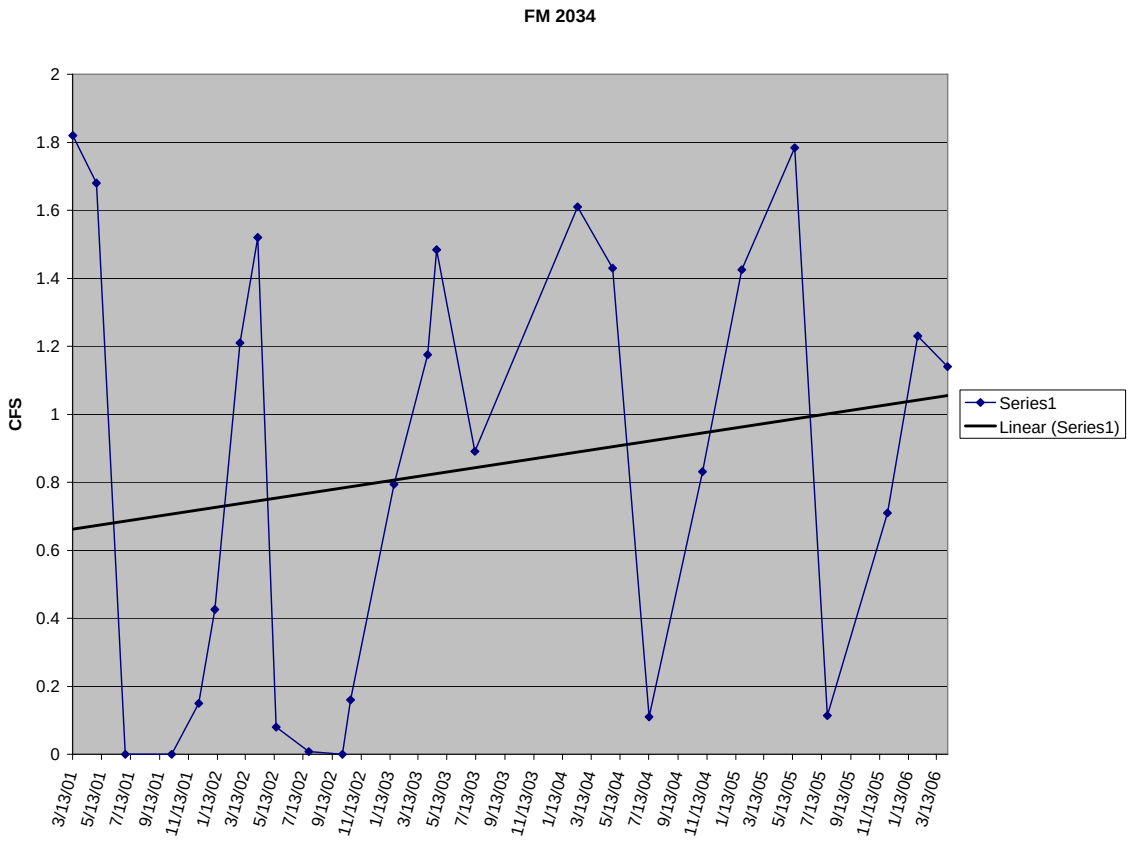


	U RANCH	STERLING CREEK	1.1mi UPST SHERWOOD XING	0.5mi UPST SHERWOOD XING	SHERWOOD XING	RAWLINGS	FM 2034	POST OAK RD	CARLSBAD	E. LOOP	FM 2288
3/29/2000					2.8		9.7	13.82			
5/9/2000								2.67			
12/7/2000					0		1.0	0.8	0	0	0.00067
1/20/2001					0		2.1	1.71	2.4	0.384	0.0013
2/5/2001					0			1.5	0.86		
3/13/2001		0.1026			0		1.82	2.14	1.4	1.04	0.352
5/2/2001		0.024			0	1.14	1.68	1.14	0.5	0.08	0.0035
7/2/2001		0			0	0	0	0	0	0	0
10/8/2001		0			0	0	0	0	0	0	0
12/4/2001		0			0	gate locked	0.15	0.16	0	0	0.013
1/7/2002		0			0	gate locked	0.426	0.058	0	0	0.0022
3/1/2002		0		0.06	0*	1.12	1.21	0.84	0	0	0
4/8/2002	0.013	0.052		0.11	0	1.15	1.52	1.988	0	0	0
5/17/2002	0	0		0.009	0	0.253	0.08	0.029	0	0	0
7/25/2002	0	0	0.054	0	0	0	0.0078	0.0063	0	0	0
10/4/2002	0	0	0	0	0	0	0	0	0	0	0
10/21/2002	0	0	0.023	0	0	0.17	0.16	0.033	0	0	0.097
1/21/2003	0	0.028	0.127	0	0	0.908	0.794	1.048	0	0	0
4/2/2003	0	0.057	0.208	0.0516	0	1.299	1.175	1.34	0.2	0	0
4/21/2003	0	0.055	0.205	0.0452	0	0.9303	1.484	0.873	0.5	0	0
7/11/2003	0	0	0.458	0.147	0	0.404	0.891	0.738	0.5	0	>0.01
2/13/2004	0	0.186	POOL	0.086	0	1.31	1.61	1.65	0.6	0	0
4/27/2004	0	0.17	POOL	0.121	0	1.1	1.43	1.75	1	0.57	0.13
7/13/2004	0	0	0.12	0	0	0.29	0.11	0	0	0	0
11/3/2004	0	0.042	POOL	0.06	0	0.925	0.831	0.223	0	0	0
1/25/2005	0.08	0.224	0.265	0.308	0	1.328	1.4253	1.474	2.2		
5/17/2005	0.06	0.2577	0.2291	0.4452	0.0038	1.078	1.784	1.868	3.5	0.678	0.48
7/25/2005	0	0.04	0.21	0.16	0	0	0.114	0	0	0	0
11/29/2005	0.15	0.31	0.356	0.58	0.24	1.36	0.71	0.85	1.6	0	0
2/1/2006	0.22	0.38	0.71	0.98	1.5	1.32	1.23	3.26	6.2	0.72	0.86
4/5/2006	0.22	0.31	0.27	0.41	0.34	0.82	1.14	1.06	1.8	0.89	0.31

(1 CFS) x 449= GPM

Graphs of the data collected along with trend lines are shown below. These graphs are listed in hydrologic segments, beginning with the upper reach of the watershed at the U Ranch and continuing downstream through the middle reaches at FM 2034, and finally at the lower reaches of the watershed at Carlsbad.




FM 2034
CFS
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
3/13/01
5/13/01
7/13/01
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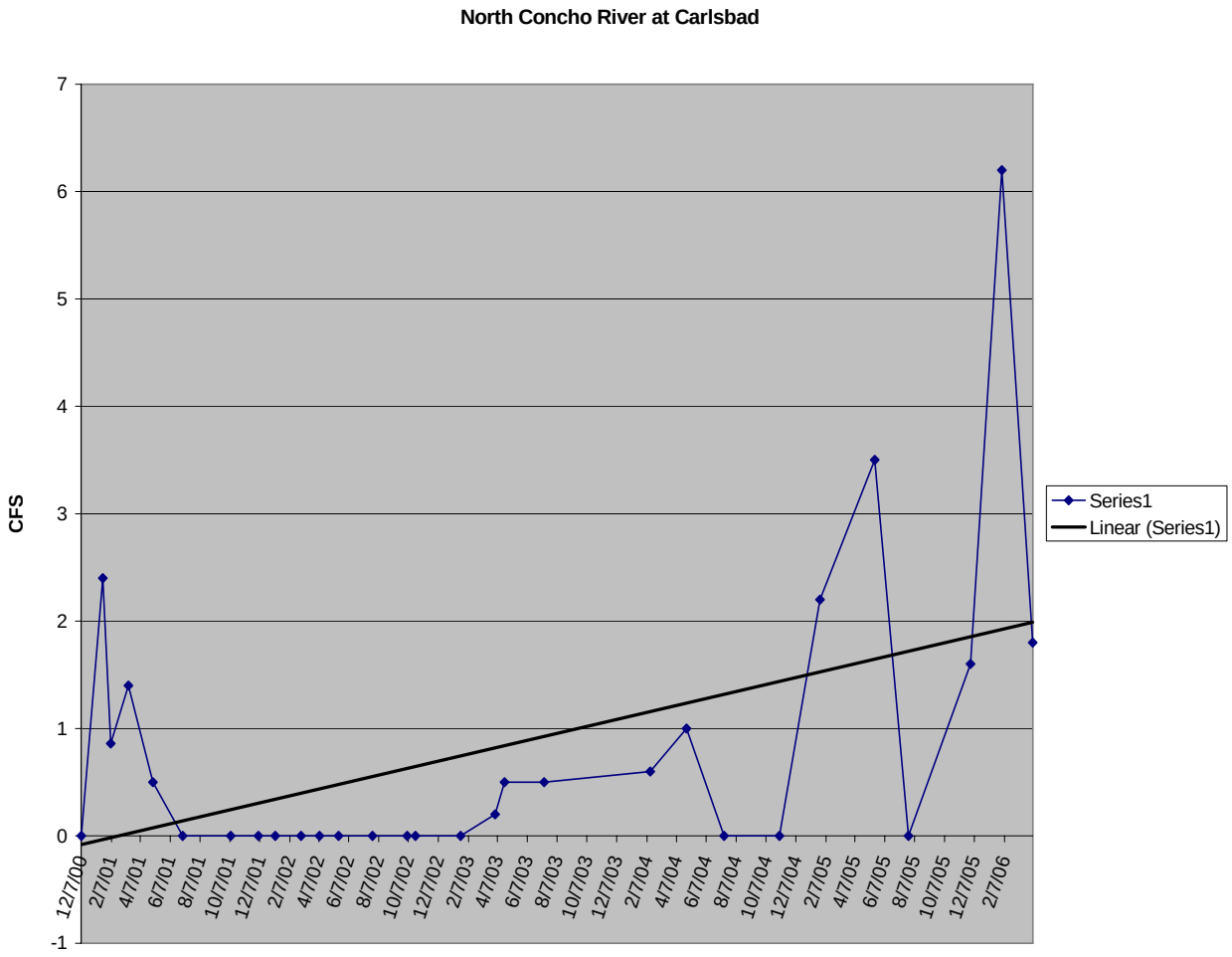
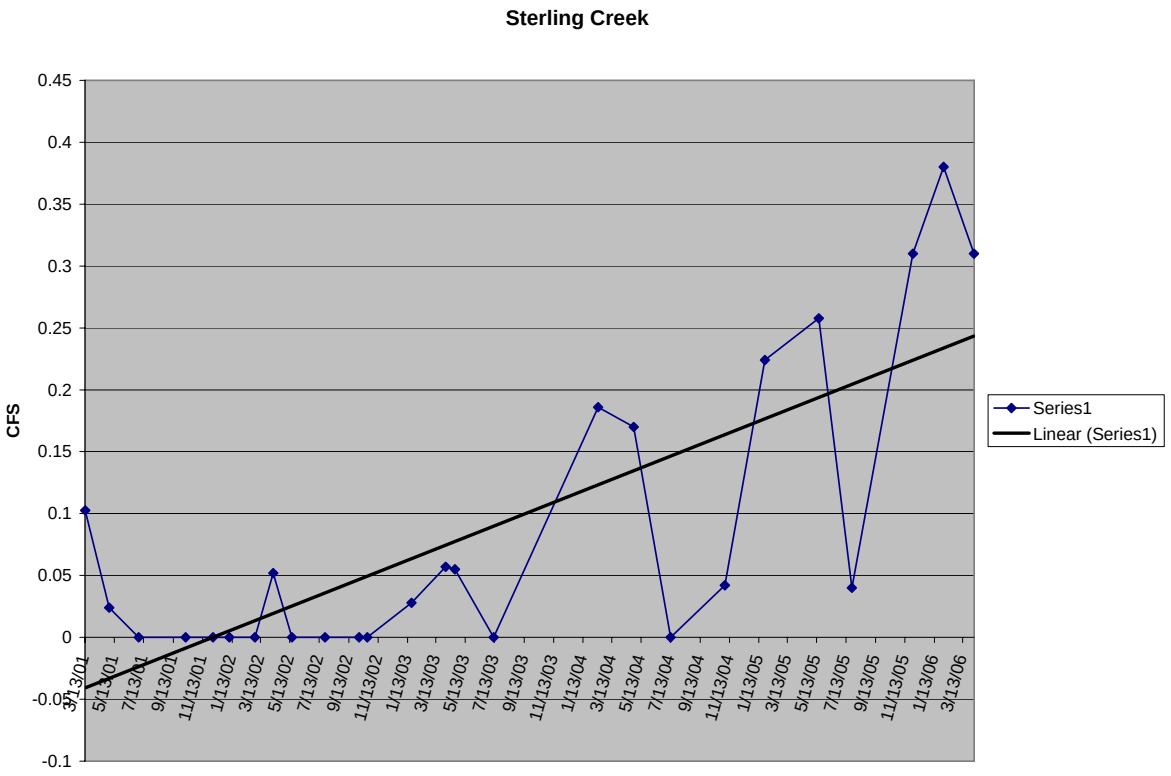
3/13/06
Series1
Linear (Series1)



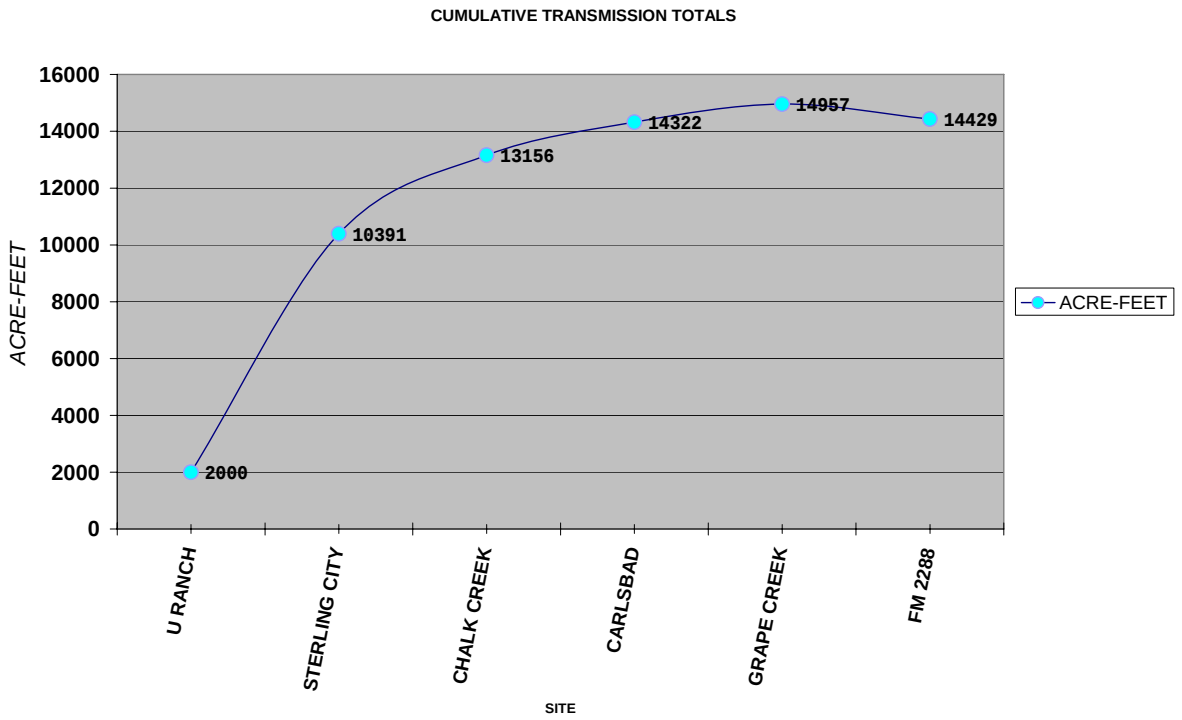
Sterling Creek, a tributary that flows into the North Concho River just below Sterling City is also showing the effects of brush control. A significant amount of the Sterling Creek watershed has been restored to the pre-brush condition and as a result, Sterling Creek has become perennial.

As shown on the following page, Sterling Creek has been flowing continuously since the fall of 2004.

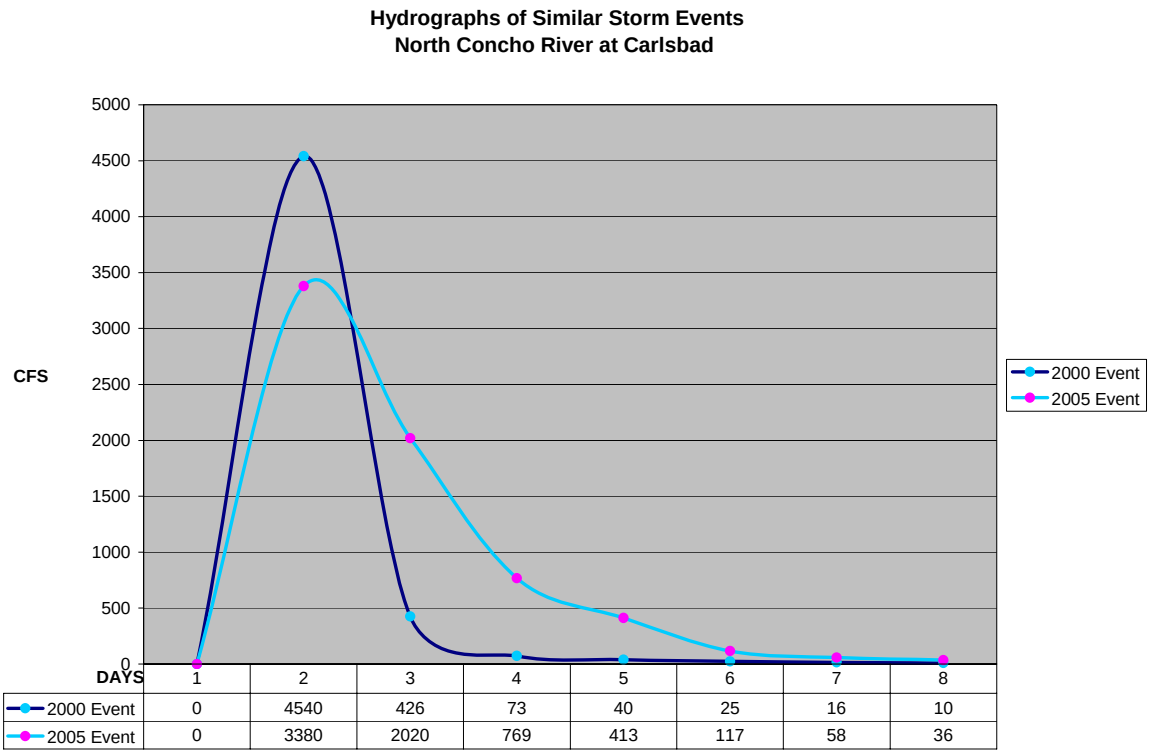


As previously shown in the surface water flow data, many of the monitoring sites had intermittent flows. This condition led to significant channel loss when rain events occurred, hence a significant reduction in the amount of water delivered to O.C. Fisher Lake. Eight run-off events occurred on the North Concho River between 2000 and 2004 when the river was not running and the channel was dry at many locations. Discharge Reports were performed on each storm event, which ranged from minor runoff events (200 CFS peak) to major events (>1000 CFS peak). These reports included Doppler rainfall estimates, USGS gaging station records and calculations of channel losses. For these eight events, the North Concho River failed to deliver on average, 66% of the water to OC Fisher that was gauged within the streambed. In some of the smaller events, >90% of the water was lost.

Conversely, as the streams along the reach became perennial, channel losses were significantly reduced. In contrast to the previously occurring storm events, one that occurred in August 2005 when the river channel was saturated, delivered 96% of the gauged stormwater to OC Fisher Lake. A graph of cumulative transmission totals follows.



For comparative analysis, hydrographs from the August 2005 storm and a similar storm that occurred in March of 2000 are shown on the following page. Both events occurred in the upper reaches of the watershed with very similar characteristics. Fifty percent of the water that flowed down the North Concho River during the 2000 storm did not make it to OC Fisher due to channel transmission losses. Additionally, it is important to note the different slopes of the hydrographs. Most significant is the slope of the falling limb. The falling limb of the 2005 event has a much more gradual decline than the one from the 2000 event. This indicates that a greater percentage of storm generated runoff is being delivered downstream. Not only is more runoff delivered downstream, but the more gradual slope also illustrates that the runoff event is sustained over a longer time interval. The shape of the 2005 storm event hydrograph is indicative of a much healthier ecological condition than the shape of the 2000 storm event hydrograph. It also represents a return to the hydrograph shapes that were typical of storm events occurring prior to 1960.



DAYS	1	2	3	4	5	6	7	8
2000 Event	0	4540	426	73	40	25	16	10
2005 Event	0	3380	2020	769	413	117	58	36

Ground Water Observations

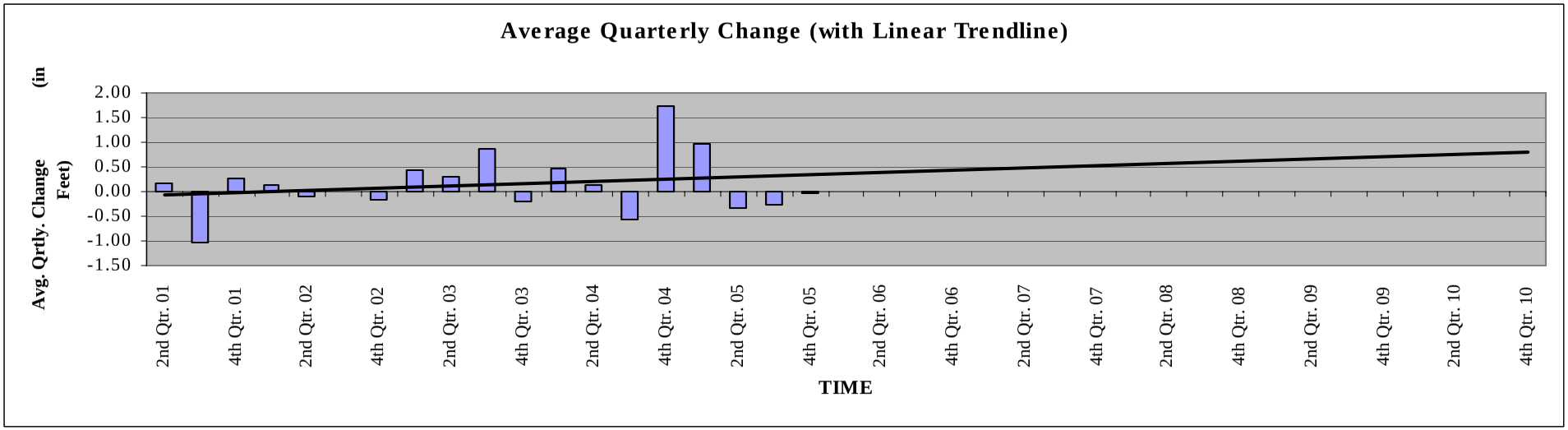
Ground water static elevations are regularly measured by the UCRA. A total of twenty-three (23) wells located in Tom Green and Coke Counties are regularly monitored by the UCRA in the North Concho river watershed. This number varies as access to some wells is lost and replacement wells are added. An additional eighteen (18) wells located in Sterling County are gauged on a quarterly basis by the Sterling County Underground Water Conservation District. Several of the original wells being monitored have become inaccessible due to various causes and can no longer be monitored. Nearby replacement wells have been added in some instances and replacements for others have yet to be located. Moreover, areas of needed additional coverage within the watershed have been identified. Suitably located replacement wells and additional coverage wells (owned by landowners who will allow access) are continually sought.

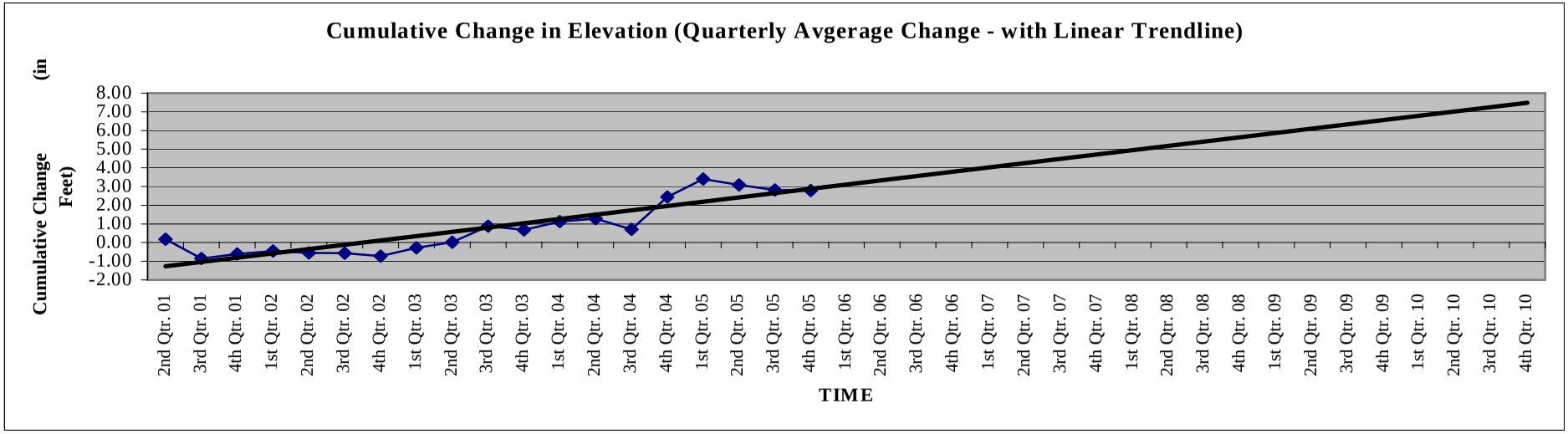
Discrete monitoring event changes as well as cumulative changes in measured static groundwater elevations are tabulated and graphed for each well that is monitored. For each monitoring event, wells are sorted into three categories, i.e.

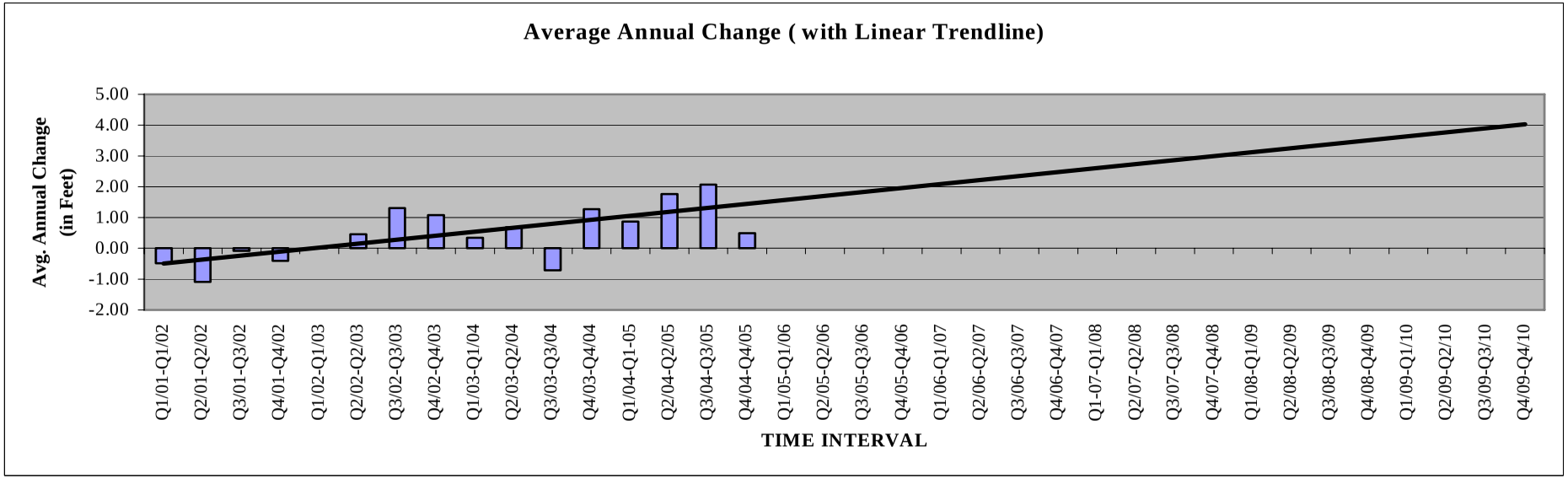
wells in which a decline, a steady state, or a rise in measured hydrostatic elevation has occurred relative to the previous measurement. These data are tabulated and graphed.

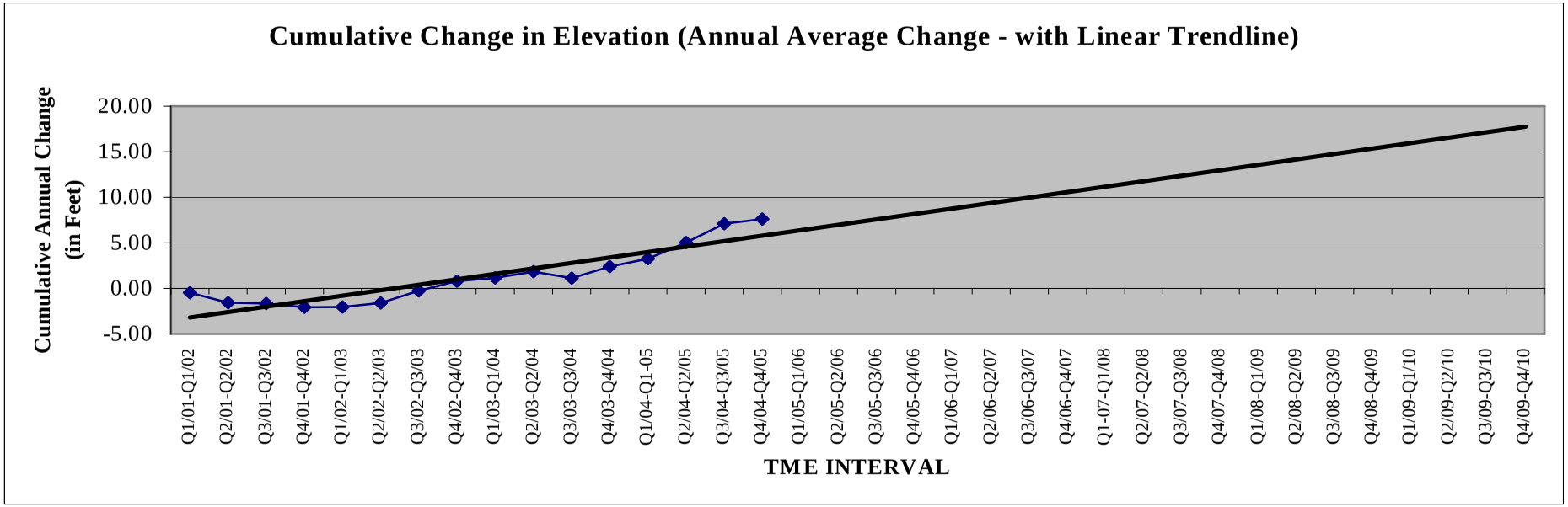
On the graphs presented that follow, cumulative quarterly average changes and cumulative annual average changes in static groundwater levels are plotted with trend-lines added. These graphs provide an illustration of hydrostatic groundwater changes through time and an indication of the direction of change in regional groundwater hydrostatic elevations.

The cumulative changes that are illustrated on the graphs illustrate that hydrostatic ground water elevations are trending upward. As previously mentioned, an all-inclusive accounting of water inputs and outputs on a watershed scale is impossible to achieve. As a result, the determination of unerring cause and effect relationships for the observed hydrologic phenomena is also impossible. However, given that the only identified significant change that has taken place on the watershed over the monitoring period is brush control, it is reasonable to conclude that brush control is the dominant cause for the observed positive hydrologic effects on ground water elevations. The data indicate that alluvial aquifers are being recharged and holding more of the recharge water in storage for longer periods of time; or put another way, the aquifers are not being constantly depleted by deep-rooted mesquites. Moreover, the groundwater that moves from the uplands to riparian areas is not being intercepted by deep-rooted upland mesquites and is able to supply more recharge water to the riparian alluvial aquifers. Therefore, the recharged alluvial aquifers are able to sustain base flows for longer periods of time and curtail major channel transmission losses during storm events.


Average Quarterly Change (with Linear Trendline)
Avg. Qrtly. Change (in Feet)
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
2nd Qtr. 01
4th Qtr. 01
2nd Qtr. 02
4th Qtr. 02
2nd Qtr. 03
4th Qtr. 03
2nd Qtr. 04
4th Qtr. 04
2nd Qtr. 05
4th Qtr. 05
2nd Qtr. 06
4th Qtr. 06
2nd Qtr. 07
4th Qtr. 07
2nd Qtr. 08
4th Qtr. 08
2nd Qtr. 09
4th Qtr. 09
2nd Qtr. 10
4th Qtr. 10
TIME


Cumulative Change in Elevation (Quarterly Avgerage Change - with Linear Trendline)
Cumulative Change (in Feet)
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
2nd Qtr. 01
3rd Qtr. 01
4th Qtr. 01
1st Qtr. 02
2nd Qtr. 02
3rd Qtr. 02
4th Qtr. 02
1st Qtr. 03
2nd Qtr. 03
3rd Qtr. 03
4th Qtr. 03
1st Qtr. 04
2nd Qtr. 04
3rd Qtr. 04
4th Qtr. 04
1st Qtr. 05
2nd Qtr. 05
3rd Qtr. 05
4th Qtr. 05
1st Qtr. 06
2nd Qtr. 06
3rd Qtr. 06
4th Qtr. 06
1st Qtr. 07
2nd Qtr. 07
3rd Qtr. 07
4th Qtr. 07
1st Qtr. 08
2nd Qtr. 08
3rd Qtr. 08
4th Qtr. 08
1st Qtr. 09
2nd Qtr. 09
3rd Qtr. 09
4th Qtr. 09
1st Qtr. 10
2nd Qtr. 10
3rd Qtr. 10
4th Qtr. 10
TIME


Average Annual Change (with Linear Trendline)
Avg. Annual Change (in Feet)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
Q1/01-Q1/02
Q2/01-Q2/02
Q3/01-Q3/02
Q4/01-Q4/02
Q1/02-Q1/03
Q2/02-Q2/03
Q3/02-Q3/03
Q4/02-Q4/03
Q1/03-Q1/04
Q2/03-Q2/04
Q3/03-Q3/04
Q4/03-Q4/04
Q1/04-Q1-05
Q2/04-Q2/05
Q3/04-Q3/05
Q4/04-Q4/05
Q1/05-Q1/06
Q2/05-Q2/06
Q3/05-Q3/06
Q4/05-Q4/06
Q1/06-Q1/07
Q2/06-Q2/07
Q3/06-Q3/07
Q4/06-Q4/07
Q1-07-Q1/08
Q2/07-Q2/08
Q3/07-Q3/08
Q4/07-Q4/08
Q1/08-Q1/09
Q2/08-Q2/09
Q3/08-Q3/09
Q4/08-Q4/09
Q1/09-Q1/10
Q2/09-Q2/10
Q3/09-Q3/10
Q4/09-Q4/10
TIME INTERVAL


Cumulative Change in Elevation (Annual Average Change - with Linear Trendline)
Cumulative Annual Change (in Feet)
20.00
15.00
10.00
5.00
0.00
-5.00
Q1/01-Q1/02
Q2/01-Q2/02
Q3/01-Q3/02
Q4/01-Q4/02
Q1/02-Q1/03
Q2/02-Q2/03
Q3/02-Q3/03
Q4/02-Q4/03
Q1/03-Q1/04
Q2/03-Q2/04
Q3/03-Q3/04
Q4/03-Q4/04
Q1/04-Q1-05
Q2/04-Q2/05
Q3/04-Q3/05
Q4/04-Q4/05
Q1/05-Q1/06
Q2/05-Q2/06
Q3/05-Q3/06
Q4/05-Q4/06
Q1/06-Q1/07
Q2/06-Q2/07
Q3/06-Q3/07
Q4/06-Q4/07
Q1-07-Q1/08
Q2/07-Q2/08
Q3/07-Q3/08
Q4/07-Q4/08
Q1/08-Q1/09
Q2/08-Q2/09
Q3/08-Q3/09
Q4/08-Q4/09
Q1/09-Q1/10
Q2/09-Q2/10
Q3/09-Q3/10
Q4/09-Q4/10
TME INTERVAL

HYDROLOGICAL RESEARCH PROJECTS

Evapotranspiration Studies (Honey Mesquite)
See Appendix A

Surface Runoff Studies (Juniper
See Appendix B

Continuous Groundwater Monitoring
See Appendix C

Grape Creek Project
The watersheds of the East Fork and West Fork of Grape Creek are each approximately 25,000 acres in size. Approximately 75-80% of the acreage comprising the watershed of the East Fork of Grape Creek has been mechanically cleared of mesquite and Juniper. With the exception of only a few acres (<300), the watershed of the West Fork of Grape Creek has received no brush treatment.

Following significant rains that fell over the area of these adjacent watersheds in November 2004, the East Fork of Grape Creek began to exhibit base flows. Beginning in January 2005, the UCRA gained permission from the landowners of both watersheds and began periodically measuring flows at various fixed sites on the East Fork and West Fork of Grape Creek. Flow measurements are obtained at fixed sites that cover the entire stream-reach of the East and West Fork from the source springs to sites located just above their confluence.

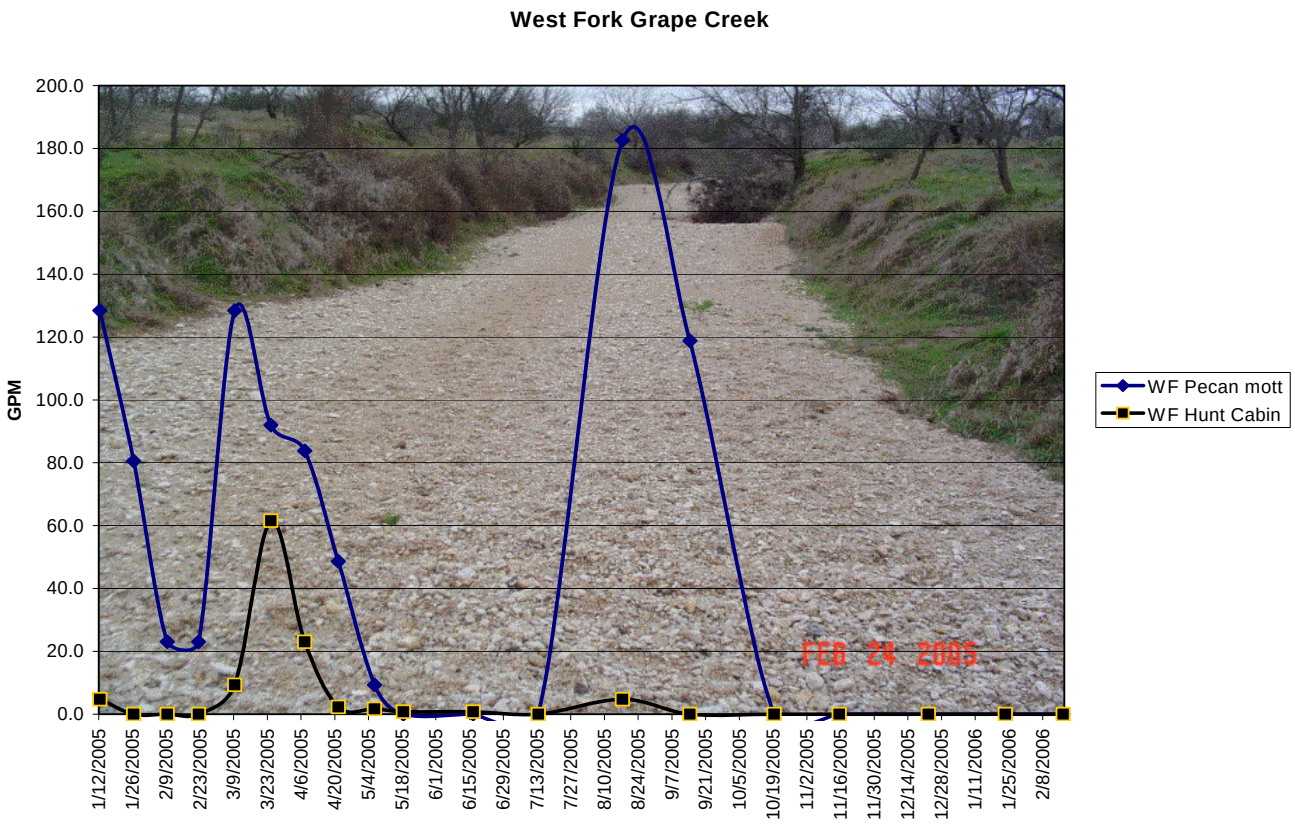
Cumulative base flows for the East Fork of Grape Creek for all of 2005 plus the first quarter of 2006 equal 2,025 acre feet. The mean annual flow for 2005 calculates to 2.61cfs. These values are based on the measured flows at the measurement site located furthest downstream (just above the confluence with the West Fork of Grape Creek). Although some base flows were measured in the upper reaches of the West Fork of Grape Creek, channel transmission losses resulted in no net flow at the furthest downstream measurement site (located just above the confluence with the East Fork of Grape Creek).

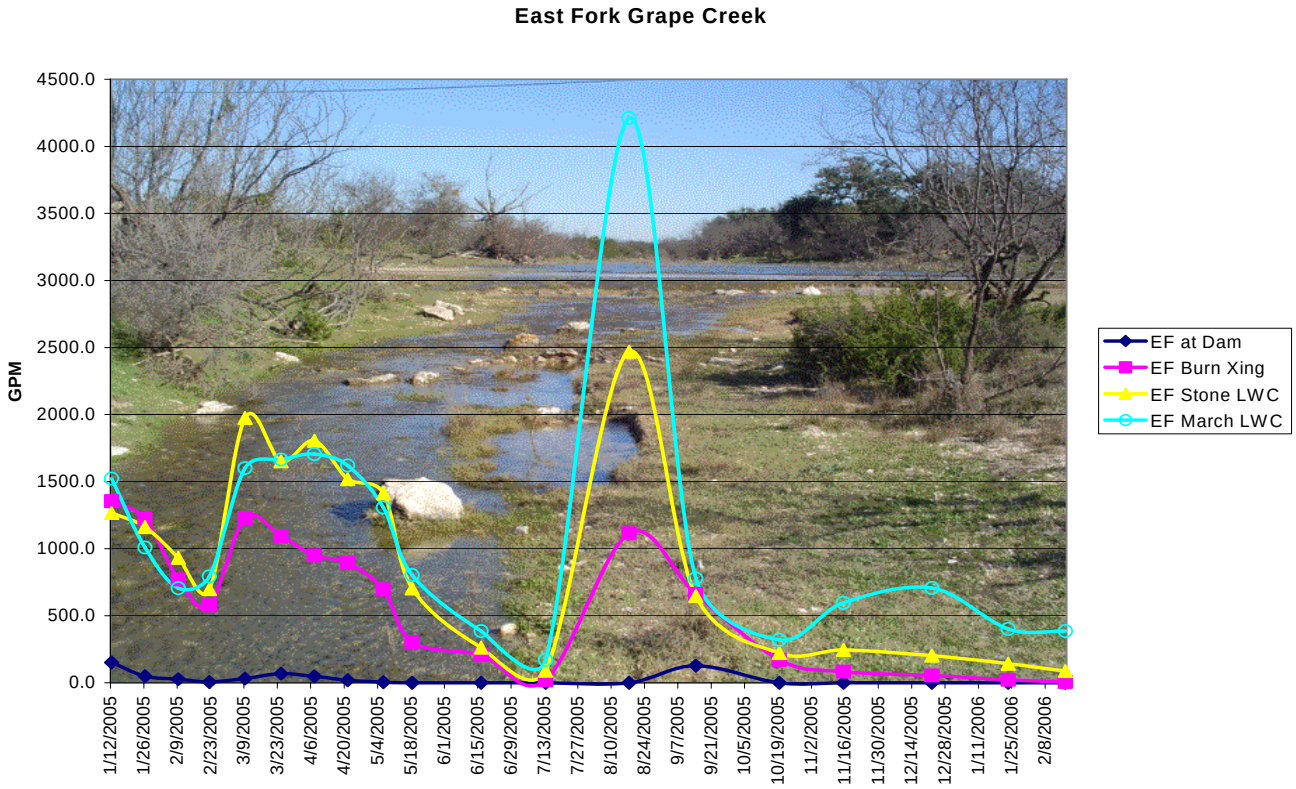
On February 23, 2005, the UCRA installed pressure transducers in the streambeds of the East and West Forks of Grape Creek at the furthest downstream measurement sites of each. These were installed for the purposes

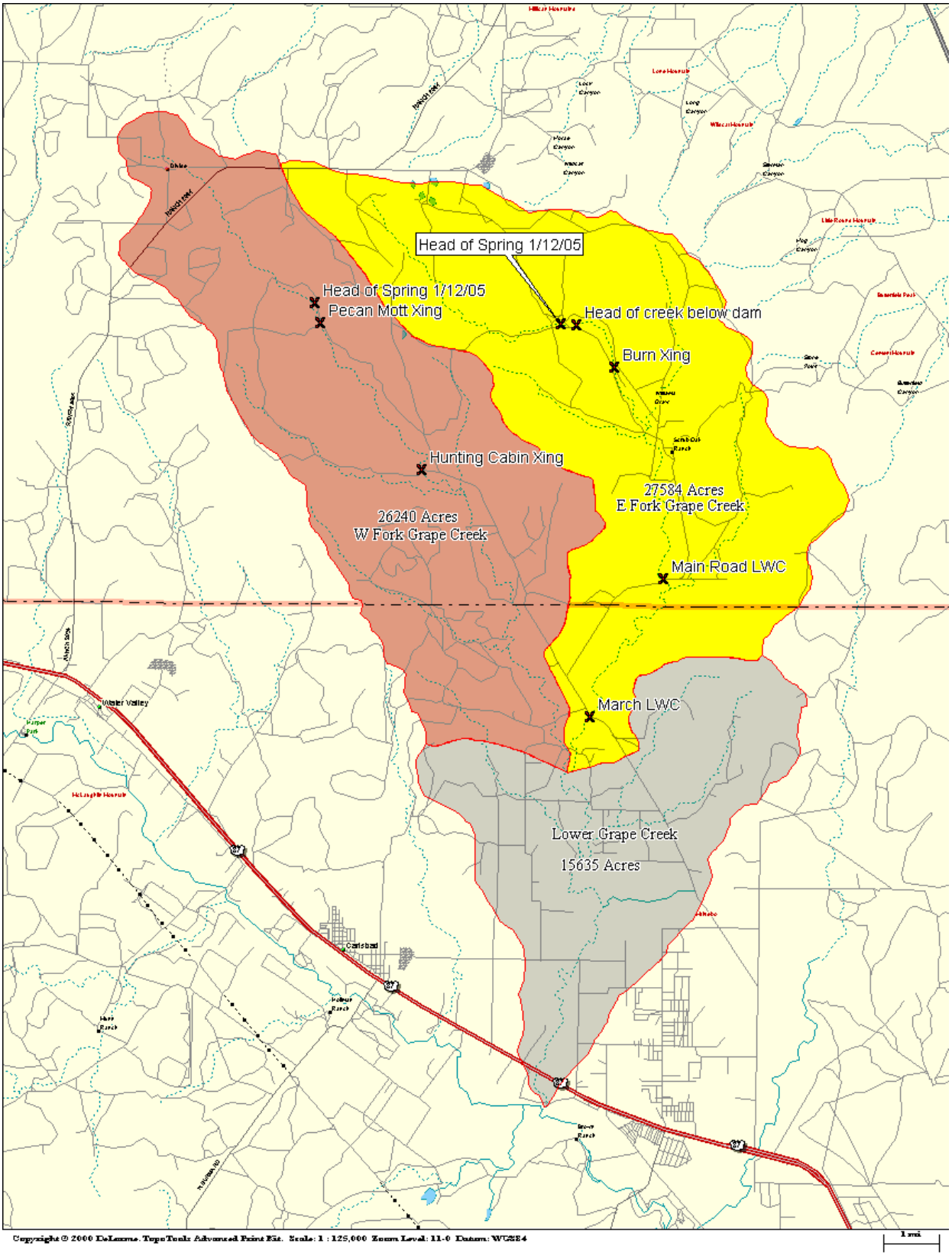
of measuring storm event runoff. There have not been enough runoff events and thus, not enough data collected to generate rating curves for either site. Consequently, a quantitative assessment of how much storm water runoff has passed each of these transducers has not been possible. However, it should be noted that during most of the rainfall events that have occurred on the watersheds, the East Fork of Grape Creek experiences small runoff events while the West Fork does not. These small runoff events occur even during relatively minor rainfall events. This phenomenon illustrates the benefit of having perennial conditions existent within a watershed, i.e. even small rainfall events contribute to the total stream conveyance. Conversely, the West Fork of Grape Creek experienced no such benefits from these small rainfall events.

Another meaningful observation, resulting from the work performed by UCRA on Grape Creek, relates to the different characteristics exhibited by the East and West Forks of Grape Creek during a large runoff event that occurred on both watersheds in the middle of August 2005. While the West Fork experienced a large, flashy, one day event, the East Fork experienced not only a large, one day event, but also had significantly increased flows for several days afterward. Moreover, the pools of water that existed in the channel of the West Fork of Grape Creek after the runoff event were rapidly lost to groundwater recharge into depleted alluvial aquifers. This event was the only event for the entire year of 2005 and the first quarter of 2006 during which the West Fork of Grape Creek conveyed any water past its confluence with the East Fork of Grape Creek.

There exists no known plausible cause for the different hydrological behaviors displayed by these two watersheds other than brush control. These flow data are tabulated and graphed below


West Fork Grape Creek
GPM
200.0
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
FEB 24 2005
1/12/2005
1/26/2005
2/9/2005
2/23/2005
3/9/2005
3/23/2005
4/6/2005
4/20/2005
5/4/2005
5/18/2005
6/1/2005
6/15/2005
6/29/2005
7/13/2005
7/27/2005
8/10/2005
8/24/2005
9/7/2005
9/21/2005
10/5/2005
10/19/2005
11/2/2005
11/16/2005
11/30/2005
12/14/2005
12/28/2005
1/11/2006
1/25/2006
2/8/2006
WF Pecan mott
WF Hunt Cabin


East Fork Grape Creek
GPM
4500.0
4000.0
3500.0
3000.0
2500.0
2000.0
1500.0
1000.0
500.0
0.0
1/12/2005
1/26/2005
2/9/2005
2/23/2005
3/9/2005
3/23/2005
4/6/2005
4/20/2005
5/4/2005
5/18/2005
6/1/2005
6/15/2005
6/29/2005
7/13/2005
7/27/2005
8/10/2005
8/24/2005
9/7/2005
9/21/2005
10/5/2005
10/19/2005
11/2/2005
11/16/2005
11/30/2005
12/14/2005
12/28/2005
1/11/2006
1/25/2006
2/8/2006
EF at Dam
EF Burn Xing
EF Stone LWC
EF March LWC


Head of Spring 1/12/05
Head of Spring 1/12/05
Pecan Mott Xing
Head of creek below dam
Burn Xing
Hunting Cabin Xing
27584 Acres
E Fork Grape Creek
26240 Acres
W Fork Grape Creek
Main Road LWC
March LWC
Lower Grape Creek
15635 Acres
Carlsbad
Copyright © 2000 DeLorme. TopoTools Advanced Point Kit. Scale: 1 : 125,000 Zoom Level: 11-0 Datum: WGS84
1 mi

APPENDIX A

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INTERIM REPORT
Effect of Brush Control on Evapotranspiration

Abstract

An on-going project that is designed to study changes in total water budget with implementation of brush control using paired-watershed comparisons is summarized in this paper. The paired watersheds are located near San Angelo, Texas in a flat, mesquite-dominated area with relatively deep soils in northern Tom Green County. Each of the watersheds consists of about 200 acres. Evapotranspiration (ET) from the mesquite plants was initially (beginning 1999) measured by Bowen Ratio (BR) technique. However, because of numerous problems associated with this technique, the ET has additionally been measured using Eddy Covariance (EC) technique since April 2004. The measured data quality has improved significantly since using the EC technique. The mesquite trees in the treated watershed (site M1) were killed by herbicide in June 2002. The management practices in the other watershed (site M2) remained the same during the study period. Measured data during the growing season (April through October 2005) indicate that ET values on the mesquite-treated watershed (site M1) are about seven percent lower than those of the untreated watershed (site M2). The results also show that ET at site M2 is more pronounced (about 13 percent higher than site M1) during the peak of mesquite growing season (June through October, 2005). This increase appears to be due to greater water uptake from deeper soil profiles at site M2 due to the presence of full grown mesquites. However, after the end of the mesquite growing season (October through December 2005) the ET at site M1 increases slightly above that measured at site M2 because of higher live grass population at site M1 as compared to site M2.

Introduction

Consumptive water use in the western United States exceeds recharge, leading to a significant depletion of aquifers and stream flows throughout much of the region. It is believed that water yield from rangeland on such regions is significantly greater if the site is dominated by grass instead of brush. Therefore, brush control programs are being considered by policy-makers as a way to relieve water shortages based on the belief that improved water yields from suitable range sites will raise groundwater levels and/or increase stream flow in the region thus benefiting off-site water users (Thurow *et al.*, 2000).

In Texas, water supply will likely be the most limiting natural resource in the future (Texas Water Development Board, 1997). The increasing Texas population and associated municipal and industrial growth are placing greater demands on the state's water supply. The issue of available supply is particularly acute during times of drought, as was learned during the drought of the late 1990s to 2001 (Wilcox *et al.*, 2005). It has been estimated by the U.S. Natural Resources Conservation Service (Walker *et al*., 1998) that the brush in Texas uses about 10 million acre-feet of water per year, while there is 15 million acre-feet used by human. Therefore, brush control seems to affect water resources by enhancing the surface water supplies, recharge of groundwater aquifers and spring flow.

Honey mesquite, one of the brush species growing in Texas, has deep taproots, which enable the plant to avoid drought (Ansley *et al.*, 1990). Thus, prolonged drought conditions could reduce perennial forage, and favor mesquite survival due to its deeper rooting (Warren *et al.*, 1996). In addition, mesquite establishes under a wide range of

conditions and withstands repeated top removal because it is a prolific producer of long-lived seeds that germinate readily after scarification (Laxson *et al.*, 1997). Furthermore, the mesquite density and distribution have been increasing. The factors that contribute to this increase usually include: 1) rangeland management practices; 2) enhanced seed distribution; 3) reduced grass competition from livestock grazing; and 4) climatic changes and increasing atmospheric carbon dioxide (Ansley *et al.*, 2001). The invasion of mesquite also has influenced density and production of native grasses, which are the principle ground cover and forage for livestock (Tiedemann and Klemmedson, 2004).

The North Concho River watershed is one of the watersheds in which the water resources are strongly suspected to be negatively affected by the growing brush. This watershed encompasses more than 950,000 acres located in West Central Texas within Tom Green, Sterling, Glasscock and Coke counties. The North Concho River is dammed to form O. C. Fisher Lake, which is a water supply for the city of San Angelo. However, "more than 130 million mesquite trees and more than 100 million junipers thrive in the watershed" and the trees' "tentacle roots act like straws to suck water from the watershed," according to Johnny Oswald, project manager for Texas State Soil and Water Conservation Board (TSSWCB). Selectively removing those trees is, therefore, believed to increase underground water resources for ranchers and farmers and ultimately provide more water into the North Concho and ultimately into the O.C. Fisher Reservoir (Smith, 2000).

Studies showed that the brush control can increase surface water flows and ground water recharge through reductions in evapotranspiration (ET) and rainfall interception by resident plants (Griffin and McCarl, 1989). In 1998, a study funded by

the Texas Water Development Board was conducted by the TSSWCB, Texas A&M Research and Extension Center, and the Upper Colorado River Authority (UCRA) on the North Concho River watershed to determine potential water yields from a comprehensive brush control program. This study found that the North Concho River watershed has the potential for increased water yield through brush control. It was estimated that the brush control program on the North Concho River watershed could improve water yield of the river by 33,000 acre-feet per year, a five-fold increase (Smith, 2000). Participating ranchers and landowners along with citizens and industries in San Angelo and nearby communities will benefit from a brush control program.

Theoretically, the rational for using brush management to increase water yield is established on the premise that shifting vegetation composition from species associated with high ET potential (e.g., trees and shrubs) to species with lower ET potential (e.g., grasses) will increase the likelihood of water yield, such as runoff and/or deep drainage (Thurow *et al.*, 2000). Although evaporation from the soil may increase because of less shading and more air movement, the net result of the conversion is to reduce water use. Assuming favorable soil and geological conditions for infiltration and subsurface movement of water, it follows that the water savings move downward through the soil mantle to fill up streams and ground water (Hinnert, 1983). In semi-arid rangelands, ET can account for 80-95% of the water loss. Thus, changes in woody cover in semi-arid rangelands can significantly alter ET losses and can generally increase the amount of water that percolates below the root zone into groundwater, which may, in turn, become stream flow and increased water yield (Wu *et al.*, 2001; Wilcox *et al.*, 2005).

The effect of brush control on the water budget is affected by a number of factors. For instance, brush control has been shown to increase surface runoff in some studied regions. Some studies, however, report no significant effects on surface runoff. These contradictory results occur because there are some site-specific factors affecting water yield from this practice (Lemberg *et al.*, 2002). Through a literature review, Griffin and McCarl (1989) summarized the following findings related to the brushland management: 1) water yield augmentation mainly happens in subsurface flow and ground water infiltration; 2) the rate of brush regrowth determines the time period over which water yield increases persist; 3) the method of brush control plays an important role in increasing water yield; 4) follow-up treatments are essential to maintain brush control and water yield enhancement; 5) brush management generally reduces soil erosion (in some cases, however, it may increase soil erosion); and 6) the water yield augmentation is most likely to be observed in years with high precipitation. Wilcox *et al.* (2005) also stated that the linkage between brush removal and increased water yields becomes stronger, 1) as annual rainfall increases, 2) in areas adjacent to stream channels; and 3) in upland areas where water can remove rapidly through the soil or parent material to recharge springs or shallow aquifers.

Because of the great potential for water supply increase, the Texas Agricultural Experiment Station and UCRA conducted a study to evaluate the effect of brush control on the water budget by measuring ET at paired watershed study facilities located in Tom Green County and within the Concho River watershed during the period of 1999-2001. The main objective of this study is to determine whether brush control, as a key management practice, can save water within the soil profile that would otherwise be

consumed by mesquite trees. In September of 2001, Texas Institute for Applied Environmental Research (TIAER) with collaboration of UCRA staff took responsibilities to maintain and continue collecting, analyzing, and evaluating of data from this study. The findings of this study are of importance in that they can provide an estimate of the quantity of water that could be saved by brush control for this and similar locations within the United States.

Methods and Materials

This project is based on the paired watershed study design wherein one watershed received brush control treatment and the other served as an untreated site. The untreated watershed accounts for year-to-year and seasonal variability, and its management practices remain the same throughout the study. The treated watershed has a change in management, in this case brush removal, at some point in the study. The basis of the paired watershed approach is that there are quantifiable relationships between response variables of interest, for example, ET, for the paired watersheds. The goal of the approach is to determine the statistical significance of any differences in the pre-treatment and post-treatment relationships. Because of the ability of this study design to account for meteorological variability, the paired watershed study design is typically superior to other designs in its ability to show changes in response to variables in the shortest period of time.

A. Project Background

The project area is located within the southeast portion of the North Concho River watershed (Figure 1), a watershed experiencing large-scale brush control activities.

Climate in the study area is semi-arid Average annual precipitation is 519 mm (20.45 inches) and average annual temperature is 18 °C (64.9 °F). A paired-watershed study has been established and is operational in the project area. The paired watershed consists of two adjacent areas, each approximately 81 hectares (200 acres) in size and with mesquite as the predominate cover. The mesquite paired watersheds are in an area of very low relief with an absence of discernible pathways for surface water flow. The paired watersheds are similarly instrumented and equipped to monitor a variety of pertinent variables in the soil profile and the near-surface atmosphere.

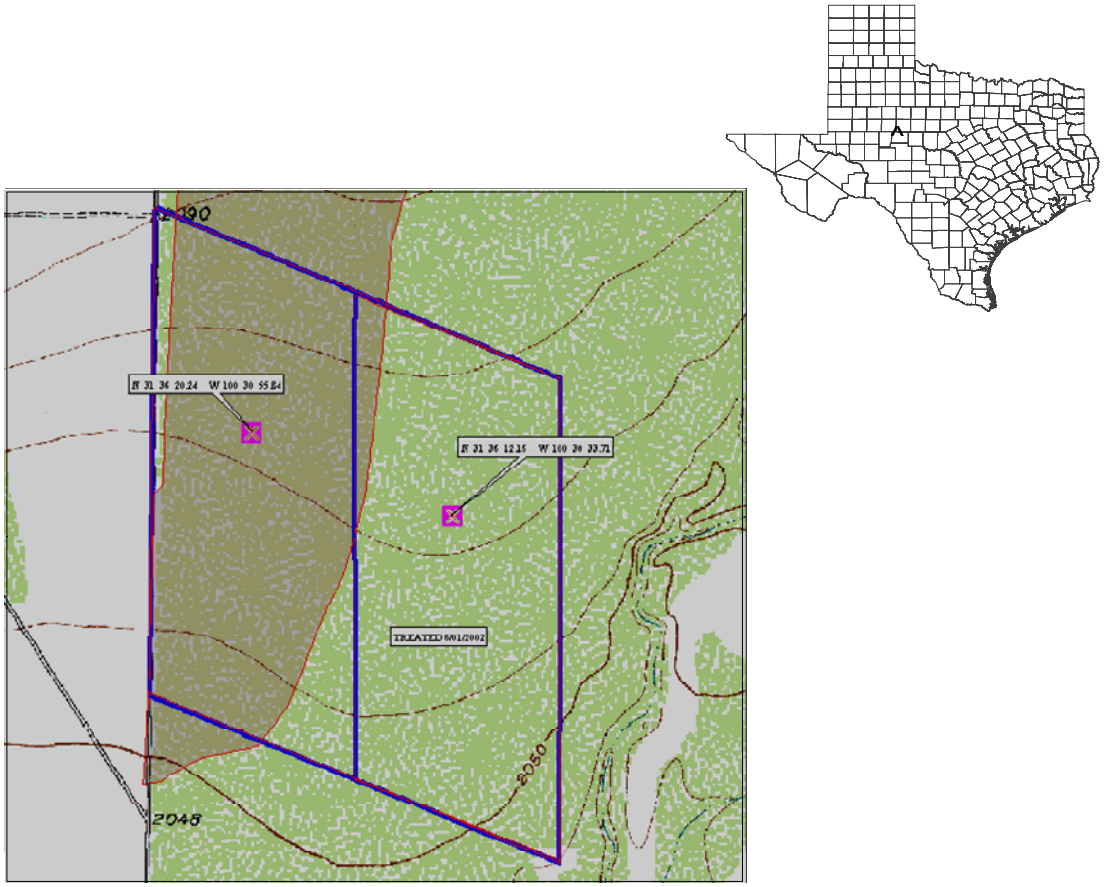

Figure 1. Locations of the treated and untreated mesquite sites near San Angelo, TX.

Two primary micrometeorological systems widely used for measuring surface scalar fluxes are the Bowen Ratio (BR) and the Eddy Covariance (EC) techniques. The BR technique directly measures net radiation, soil-surface heat conduction flux, and gradients of temperature and water vapor in the atmosphere to estimate latent heat of vaporization (LE) and heat flux (H) by assuming similarity between heat and water vapor transport and conservation of energy. The EC technique is based on direct measurements of the product of vertical velocity fluctuations and scalar concentration fluctuations, resulting in a direct estimate of H and LE assuming the mean vertical velocity is negligible (Twine *et al.*, 2000). Bidlake (2000) indicated that the EC technique offers an advantage over techniques that rely explicitly on the energy balance, such as the energy-balance BR technique, because the EC technique makes possible the direct determination of latent and sensible heat fluxes.

A 10-m meteorological tower equipped with a Campbell Scientific Data Logger was installed at the two sites in 1999. The BR technique was employed intending to obtain approximately three years of pre-treatment data to establish the baseline data which are necessary for application of the paired watershed approach. However, various complications and failures of instrumentation with the BR system had resulted in collection of much less than a complete set of reliable data. In June 2002, mesquite trees were removed from one of the mesquite sites, which represented initiation of the treatment phase of the project for the mesquite-paired watershed. Because numerous difficulties had been encountered with the BR technique used in this project, a three-dimensional eddy covariance system (Campbell Scientific, Inc., Logan, UT) was

mounted to the tower for the untreated site (referred to as site M2) in April 2004 and for the treated site (referred to as site M1) in March 2005.

The UCRA and TIAER staffs make regular visitations to all instrumentation stations. During these visitations, all equipment is checked, routine maintenance is performed, and accumulated data are downloaded. The downloaded data are then stored into a database for further review, validation, and analyses. Quality assurance and quality control (QA/QC) procedures were also established to assure that high quality data are obtained and to minimize the loss of data. In addition, by using visual inspection, graphing of data, and other appropriate techniques, such as statistical analysis, the data from each download are evaluated for suspicious data indicating malfunction of instrumentation.

On January 19, 2006 the untreated site (M2) was burned by a wildfire on January 19, 2006 started by an Arsonist. All the winter grass covering the ground was destroyed. Most of the mesquite trees surrounding the station tower were burned. Some of the EC equipment, including the battery and wires connected to the rain gage, were also damaged. By April of 2006, only the burned grass is growing back. As of May 2006, most of the burned mesquite trees have not re-foliated following this wildfire. The impact of the wildfire on the project will be evaluated in the future.

To monitor the changes of the surface plants on both untreated and treated sites, four 1-m^2 plots were randomly selected on each site since August 2005. The data in terms of the dead and live grass, grass height and grass species within the selected unit plots are inventoried regularly during the study period. The grass inventory data at the

treated and untreated sites will be valuable to those ranchers and farmers who are currently facing with insufficient beneficial grass growth in their mesquite-covered lands.

B. Eddy Covariance Technique Description

The three-dimensional eddy covariance system (Figure 2) works as follows. Vertical wind velocity is measured by a three-dimensional sonic anemometer (CSAT3) in which ultrasonic signals are pulsed between three pairs of transducers. Currently, the three-dimensional sonic anemometer among eddy covariance systems is favored because of: 1) its ability to rotate measurement axes, 2) its long-term field deployability, and 3) its ability to measure fluxes nearer the top of the canopy (Cleverly *et al.,* 2002).

Temperature is measured by a fine wire thermocouple adjacent to the sonic anemometer. Vapor pressure is measured with a krypton hygrometer (KH20), which emits an ultraviolet laser between two krypton-filled tubes (Figure 2). The eddy covariance system was oriented toward the south to take advantage of the predominant wind direction.

In this study, the latent heat flux (LE; Wm^{-2}) is computed as:

$$LE=\lambda_V \overline{w'e'} \qquad (1)$$

where λ_V (2440 $kJkg^{-1}$) is the latent heat of vaporization for water and $\overline{w'e'}$ is the 30-min covariance between the instantaneous deviation in vertical wind speed from the average vertical wind speed (w') and the instantaneous deviation in water vapor pressure (e').

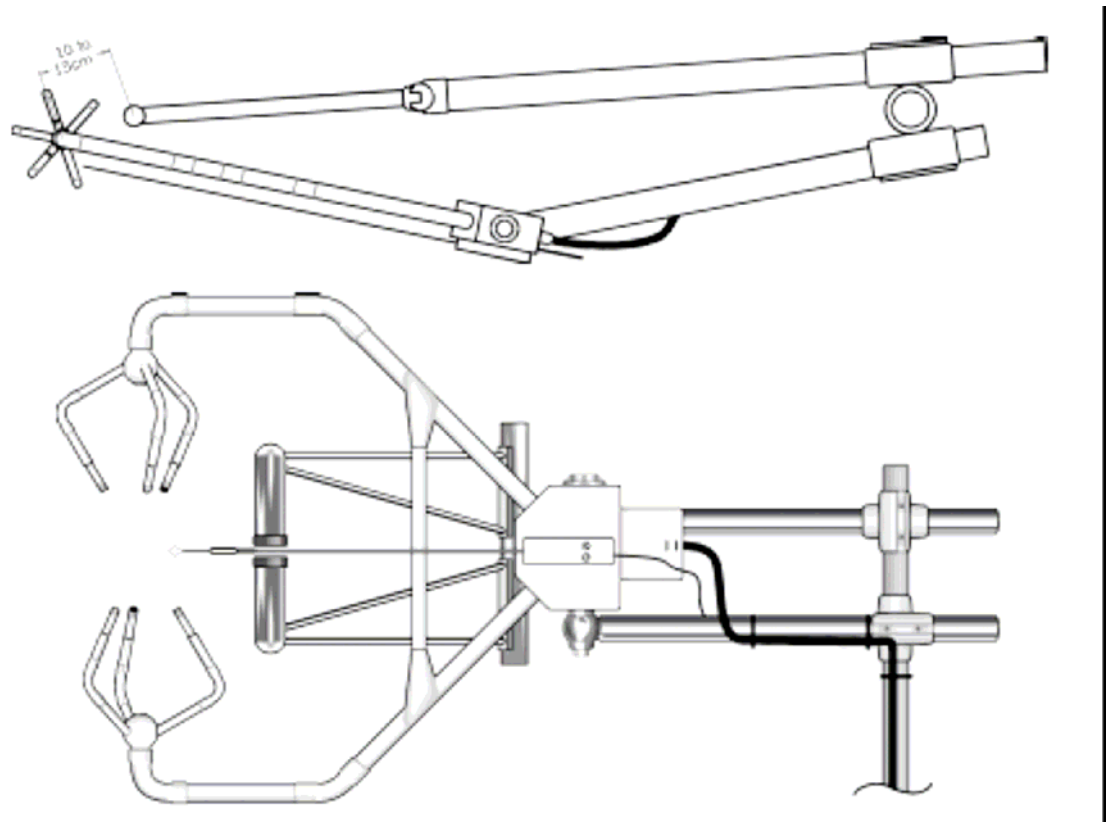

Figure 2. CSAT3 Sonic Anemometer, KH20 Krypton Hygrometer, and FW05 Fine Wire Thermocouple (Source: Campbell Scientific)

The sensible heat flux (H; Wm^{-2}) is computed as:

$$H=\rho_a C_P \overline{w'T'} \qquad (2)$$

where ρ_a (kgm^{-3}) is the density of moist air, C_P is the specific heat of air ($1004.67 Jg^{-1}{}^{o}C^{-1}$) and T' is the instantaneous deviation in temperature.

The ET (mm) from each site is computed every 30 min as:

$$ET=\frac{LE}{\lambda} \qquad (3)$$

where λ, the latent heat of vaporization, is a function of the water temperature and calculated with λ=2500-2.359T. T is the air temperature (^{o}C).

C. Data Period and Processing

Because of the numerous problems associated with the BR technique during the pre-treatment period, we actually applied herein a "modified" paired watershed approach. Hence some, if not much, of the statistical power of the "true" paired watershed study design was lost. The most reliable data obtained from the EC technique happen to be collected after the mesquite treatment at site M1. However, The changes in live mesquite trees life cycle throughout the season at sites M2 compared to treated mesquites at site M1 demonstrated the effect of mesquites on ET.

The observation period described in this paper is from April 7 to December 31, 2005. During this period, there are 12,891 observations made by the EC technique with a 30-min interval for each measurement site. Precipitation events, battery failure or other equipment failures usually cause missing data for a few hours to a few days. Since this is a paired watershed study, the 30-min ET values are calculated only when the corresponding observations from both sites are present. As a result, there are 11,472 valid observations out of the 12,891 obtained for each site. Thus, the percentage of the valid observation in 2005 is 89%.

The ET values are calculated on a daily basis, which is the sum of daytime 30-min values (during 9 am to 9 pm and when ET > 0 mm). One needs to be aware that the daily ET is not necessary to be a total of every 30-min greater than zero value during 9 am to 9 pm, because a few hours with missing data are common due to rainfall events or other equipment problems.

Results and Discussion

Overall, precipitation in 2005 was slightly higher than the long-term average. Rainfalls in February, March, May, August and October were higher than the long-term average of the corresponding months. The weather in April, June, September, November and December were extremely dry and precipitation in the remaining months was near the long-term average (Figure 3).

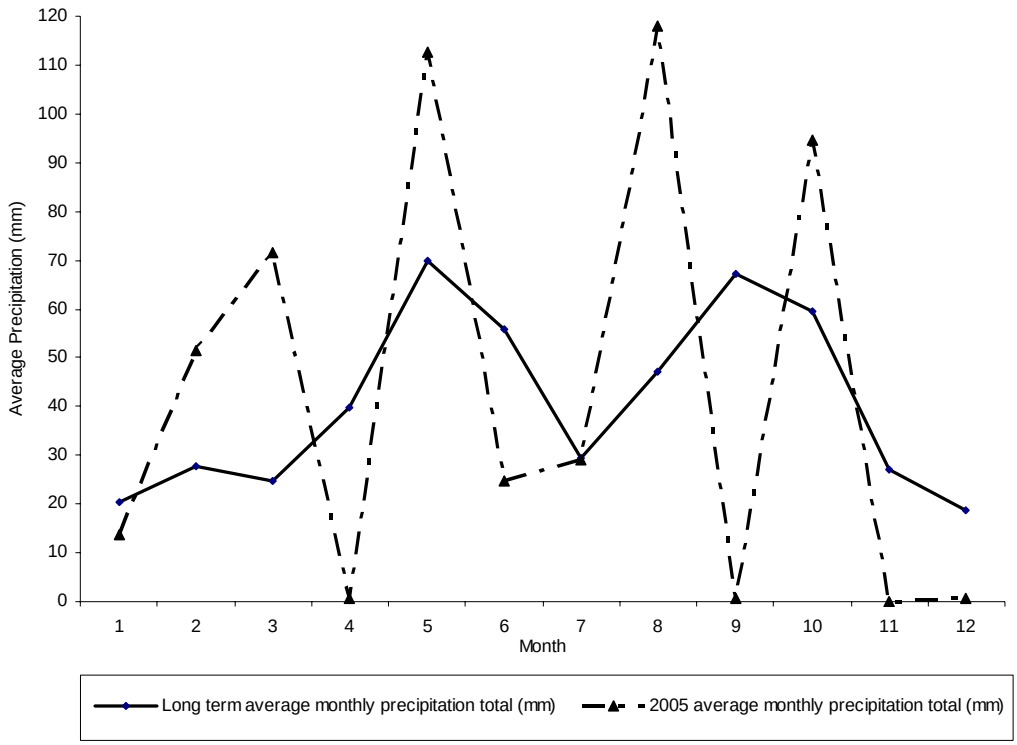

Figure 3. Long-term and 2005 average monthly precipitation recorded at measurement sites.

A. Comparison of ET obtained by the EC Technique at treated and untreated sites:

The accumulated daily ET values at the two sites obtained by the EC technique during April 7 to December 19 of 2005 are demonstrated in Figure 4. As Figure 4 shows, the accumulated daily ET at both sites are almost the same during April 7 through June

22, 2005. The field observation shows that the surface vegetation including live winter and spring grasses are full grown at both sites while the mesquite trees are about to leaf at site M2 during this period. Field observations and measured data indicate that as the grass dominance decreased and mesquite trees became the dominant vegetation during June 22 through October 15, 2005 the measured ET at site M2 increased about 13 percent as compared to what was measured at site M1 (Figures 4). This increased ET translates into significant water consumption by mesquite trees during this period. The accumulated ET at site M2 is about five percent higher than that of site M1 for the period of April 7 through December 19, 2005 (total 269 days with valid data).

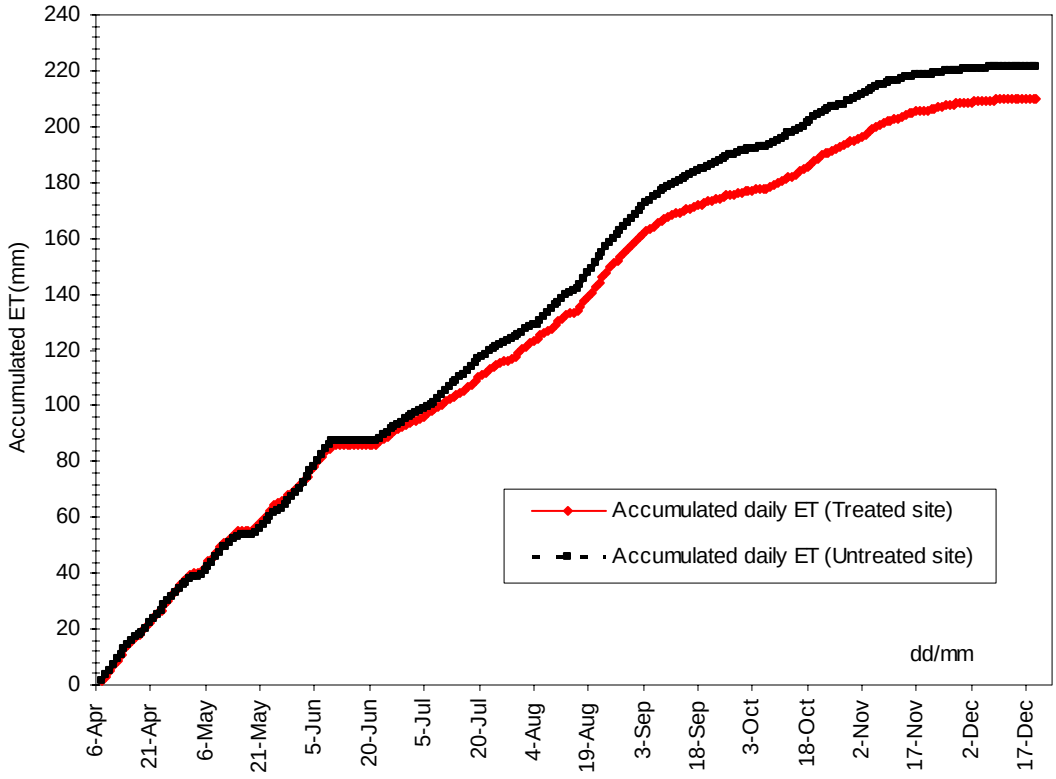

Figure 4. The accumulated daily ET obtained by EC technique at site M1 (treated) and M2 (untreated) during April 7 and December 19 of 2005

Figure 5 also shows the weekly accumulated ET at both untreated and treated sites. The weekly ET values are similar between the two sites before June 2005. However, as the mesquite trees become the dominant vegetation source during the period of June to October 2005, the measured ET at the untreated site exceeds that of treated site. Then, the ET of the treated site is slightly higher than that of untreated site during October through December 2005 (Figure 5). This pattern occurred because the mesquite growing season was over and the higher percentage of live grass at the treated site resulted in higher ET than that observed on the untreated site. The consistency of the field observation with measured values by the EC indicates the dependability and accuracy of this method for this study.

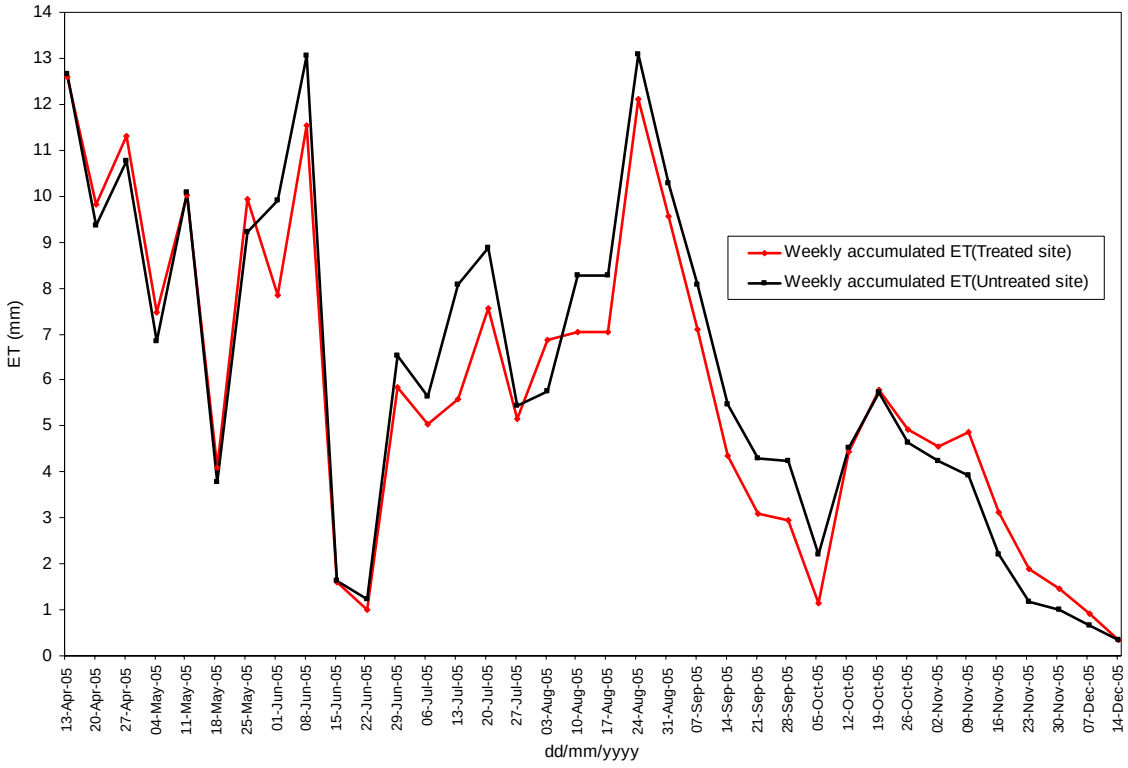

Figure 5. Comparison of weekly cumulated ET obtained by EC technique at site M1 and M2 during April 7 and December 19 of 2005

Figure 6 shows the relationship between the measured daily ET and average rainfall at the two sites during June 22 to September 30 of 2005. As indicated, the daily ET values at both sites increase following any significant rainfall events. This increase is because of the dominancy of evaporation of surface moisture provided by rainfall at both locations. However, based on similarity in level and type of grasses at both sites the ET at M2 with growing mesquite trees had higher ET during most of the period.

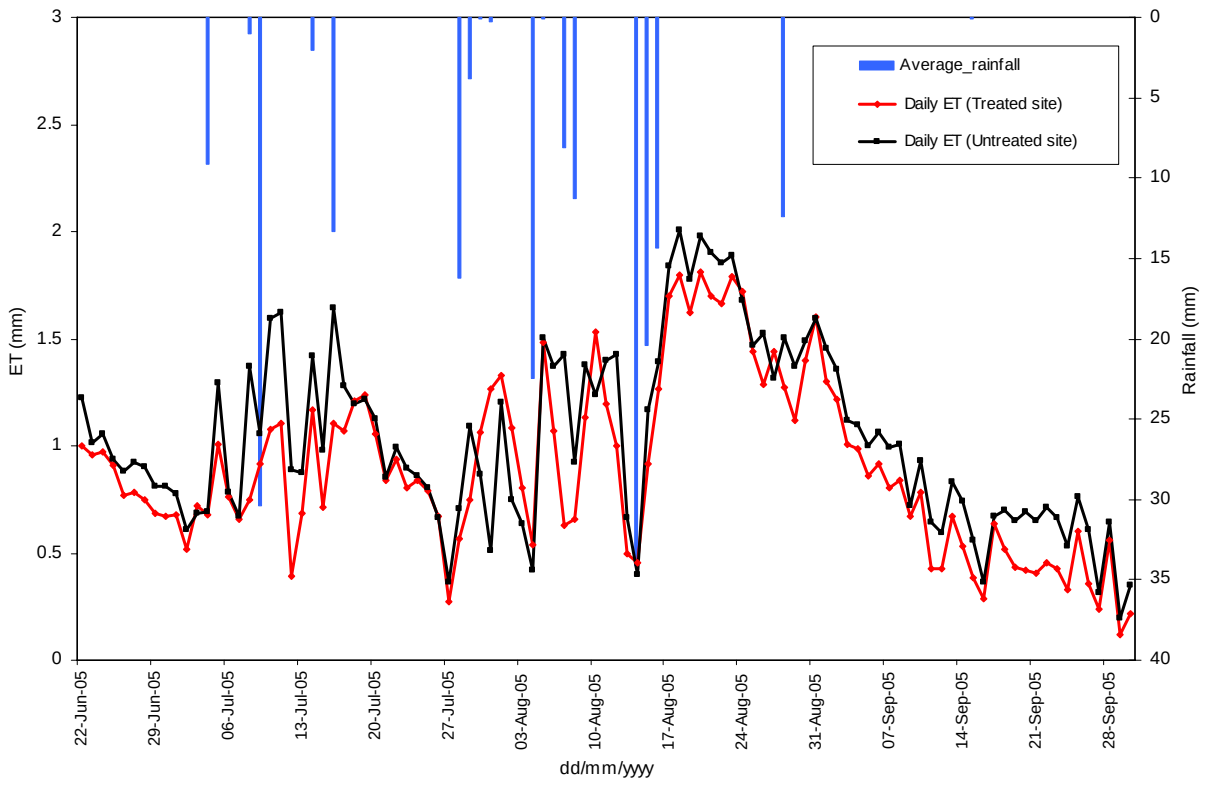

Figure 6. The daily ET obtained by EC technique at sites M1 (treated) and M2 (untreated) as related to measured average daily rainfall during June 22 to September 30 of 2005.

Summary and Conclusions

A paired watershed study is being conducted within the North Concho River watershed, located in West Central Texas. This project intends to study changes in total water budget with implementation of brush control. Field ET values are measured using the Eddy Covariance technique from two mesquite-dominated watersheds: one is a treated site in which mesquite trees were killed by herbicide; the other is an untreated site in which the management practices remain the same during the study period. The results show that the accumulated ET at the untreated site is about 13 percent higher during the peak growing season of mesquite (June through October 2005) and over 5 percent greater

during whole period of measurement (April through December of 2005) than the untreated site. This difference in ET translates to a significant amount of water consumed by the mesquite trees. The results also show that the ET from the living mesquite trees are more pronounced during the dry condition where the live grass and surface evaporation are at their lowest level. During the dry period, the ET at the untreated site is mainly obtained from the water uptake by mesquite trees from lower soil profiles, where the moisture is most available.

One needs to be aware that even though brush is removed, other vegetation will increase in density and coverage, and these species also will intercept and transpire water, leading to the difficulty to predict how much water could be "saved" by removing brush (Wilcox *et al.*, 2005). However, it is important to note that the mesquite trees compete for the moisture at the deep soil profiles which plays an important role in groundwater storage.

The recent grass inventory efforts will help us better understand the change in surface vegetation (grass) cover after brush control management. This grass inventory data at treated and untreated sites will be valuable to those ranchers and farmers who are currently faced with insufficient beneficial grass growth in their mesquite-covered lands.

Future measurements, such as moisture content at different soil layers at the treated and untreated sites, will help us better understand the soil moisture regime under these two conditions.

Finally, as this study continues, additional data collection and analysis will continue to provide: 1) better understanding of the role of brush control on the water

budget for the study area and 2) evaluation of the effect of the recent wildfire at the treated site on ET and re-vegetation growth.

Acknowledgements

This project is funded by the Texas Soil Board. The authors greatly appreciate the data collection conducted by the staff of the Upper Colorado River Authority.

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APPENDIX B

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INTERIM REPORT

Surface Runoff Studies at Juniper Sites

1. Description of juniper sites

Paired watershed sites are being monitored near San Angelo in northern Tom Green County to quantify the hydrologic effects of brush control. The pair is in a hilly, redberry juniper-dominated site with shallow soils, and it is comprised of two adjacent small watersheds, each approximately 100 acres in size. The paired juniper watersheds are still in the pre-treatment gathering phase. The juniper trees will be removed from one of the watersheds mechanically after obtaining sufficient pre-treatment runoff data from both watersheds.

2. Runoff data collection

Rainfall runoff is being monitored at the drainage outlets of the two juniper watersheds. Each watershed outlet was initially instrumented with an ISCO water-level (flowmeter) recorder set in the invert of each of two parallel corrugated pipes established in the natural conveyance of each watershed. Based on diameter, roughness, and slope of each culvert, a stage-discharge relationship was developed allowing conversion of recorded water-level to flow. Caliche and rock berms were built where necessary to ensure that runoff from each watershed was diverted through its set of two pipes. The instrumentation was installed at the outlet of both watersheds in September of 2001. Each corrugated pipe has an ISCO 3230 bubbler flowmeter installed to monitor the water level, each pipe stage-discharge relationship is used to convert water level to flow.

The ISCO 3230 bubbler flowmeter measures the water depth by converting the amount of pressure required to force an air bubbler through a 1/8 in. polyethylene tube to a water level in feet. The bubbler tube is secured to the lowest part of the flume and is surveyed to a bench mark. All flowmeters were programmed to store the data in a memory partition, which records on 5-minute intervals.

The flow sites are visited monthly for maintenance. Internal and external desiccants are replaced, battery voltage levels checked, and the current site conditions are recorded on general maintenance sheets. At each visit, the runoff data recorded by the flow meters are downloaded with a laptop computer. The downloaded data are then stored into a database for further review, validation and analyses.

In order to measure runoff from relatively small runoff events, an one-foot H flume instrumented with an ISCO 3230 bubbler flowmeter was installed at each of the two flow sites in June 2005. Each H-flume was located several feet downstream of the two corrugate pipes with berms constructed to divert all low flow into the flume. Also, in August 2005 a rain gauge was installed at each flow site.

The historical flow database was completed and is updated with the collected new data. There have been numerous problems, such as washout of corrugated pipes during a heavy storm event in June 2004, potentially significant seepage of water that bypassed the corrugated pipes during storm events, inaccurate measurement of small storm events prior to June 2005 because of the

size of corrugated pipes, and electrical problems associated with the flow recorders. Therefore, these sites have been updated with new devices, such as previously mentioned flumes, to correct some of these problems. Also, the limited number of rainfall runoff events during the last few years as result of drought conditions has resulted in an insufficient amount of pre-treatment storm runoff events to establish the necessary correlation of runoff between watersheds. The instrumentation problems and drought conditions have postponed the operation of juniper removal from the treated watershed. The juniper trees will be removed from one of the sites as soon as sufficient pre-treatment runoff data are collected to establish a statistically significant relationship of runoff between watersheds for a reasonable range of rainfall-runoff conditions.

3. Grass inventory measurement

Since August 2005, four 1-m^2 plots were randomly selected on each watershed to monitor the changes of the surface vegetation before and after the treatment. The vegetation inventory includes the record of height, species, and percentage of live and dead grasses within the replicated sampling plots. The grass inventory data before and after the treatment will be valuable to those ranchers and farmers who are currently facing insufficient beneficial grass growth on their juniper-covered lands.

4. Watershed simulation using APEX

The small watershed hydrologic/water quality model APEX (Agricultural Policy/Environmental eXtender) will be used to evaluate the effects of juniper removal on water quantity and quality based on the data from the two watersheds. Currently, the basic information, including weather, DEM (digital elevation model), soils, landuse, and management required for the APEX simulation, has been obtained. After preparation of these data, simulation of the APEX will begin. The measured runoff obtained from the two watersheds will be used to validate APEX. Then, APEX will be simulated to evaluate the juniper removal effect on the water quality and quantity scenario.

APPENDIX C

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Continuous Ground Water Monitoring Conducted in Conjunction With N. Concho River Brush Control Pilot Project Monitoring

Prepared by:

Scott McWilliams, Staff Hydrogeologist
Upper Colorado River Authority

Prepared for:

Texas Water Development Board
Contract Number 2004-483-519

August 2005

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Continuous Ground Water Monitoring
Conducted in Conjunction With
N. Concho River Brush Control Pilot Project Monitoring

INTRODUCTION

This report has been prepared pursuant to the provisions of Contract 2004-483-519, executed on April 13, 2004 and amended on September 13, 2004, between the Texas Water Development Board (TWDB) and the Upper Colorado River Authority (UCRA). The amendment extended the date for completion to January 31, 2005.

Since 1999, the UCRA has conducted a groundwater/surface water monitoring program for the Texas State Soil and Water Conservation Board's North Concho River Pilot Brush Control Project. The program's primary objective is to observe hydrologic changes in response to brush control. To that end, a significant database of surface water and groundwater measurement data has been accumulated.

Identifying trends in any kind of data requires two components: a sufficient period of time and an appropriate frequency of sampling. The former component has been addressed in that the groundwater monitoring program has been on-going for five (5) years with plans to continue it for a total of ten (10) years, subject to the availability of funds and the conclusiveness of findings. The latter component, frequency of measurement, is being addressed for surface flows by several USGS stream gaging stations located throughout the North Concho River Watershed. However, there has

been no continuous monitoring of the alluvial aquifers nor estimates made of the consumptive use of alluvial groundwater by mature mesquite forests that exist over much of the watershed.

The TWDB provided funds and equipment to the UCRA to continuously monitor groundwater levels from selected wells situated in alluvial aquifers of the North Concho River Watershed. The initial proposal, prepared in January 2004 called for the installation of pressure transducers in three to six (3 - 6) wells for a period of six (6) months. In addition to these level-loggers, conjunctive use of up to ten (10) float and pulley chart recorders was planned. At the time of preparation of the grant application, three landowners had offered the use of wells located on their property for the study. One landowner had volunteered the use of ten wells situated on Walnut Creek, a tributary of the North Concho River, for the installation of float and pulley chart recorders. Two (2) other landowners had given permission for the use of a total of three wells located in the Chalk Creek sub-watershed, also a tributary of the North Concho River.

Shortly after the execution of the contract in April 2004, an on-site tour and inspection of the ten (10) wells offered by the Walnut Creek landowner revealed that none of the wells were suited for installation of float and pulley chart recorders. Thus, conducting the continuous groundwater level measurements on the Walnut Creek watershed, on which the proposed study was based, was rendered impractical. All the wells were being utilized with electric pumps or windmills, or were obstructed or plugged. Access for periodic manual measurement of the wells with submersible pumps was precluded by the surface equipment configuration. Moreover, the use of windmills for groundwater level monitoring has been abandoned by the UCRA because of recurring instances of e-line probes becoming lodged between the tubing and the casing, resulting in the loss of probes downhole. Obviously, these unfortunate circumstances rendered the Walnut Creek portion of the project impossible. Although a component of the monitoring program of the North Concho River Pilot Brush Control Project is the continuing search for additional privately owned monitor wells to be added to those currently being monitored, no suitable substitute wells for the Walnut Creek portion of the project were discovered.

Moreover, one of the Chalk Creek landowners withdrew permission for the use of his well because of his planned installation of a windmill in the formerly open, cased well. These unfortunate events reduced the data gathering opportunity to the two remaining wells located within the Chalk Creek sub-watershed.

GEOLOGY AND HYDROGEOLOGY DESCRIPTION

The geology of the study area is comprised of Quaternary aged alluvial deposits that unconformably overlie the Antlers Sand of Cretaceous age which, in turn unconformably overlies Permian aged rocks (Lee, 1986). In the downstream stretches of the North Concho River Valley, erosional down cutting has truncated the Antlers Sand and the alluvial deposits unconformably overlie Permian aged rocks. Chalk Creek is located near the subcrop contact between the Permian aged Quartermaster Formation and Whitehorse Sandstone Member of the Woodward Formation (Bureau of Economic Geology, 1976). The alluvial deposits consist of channel lag, point bar, meander bar, channel fill, valley fill, and flood plane deposits. Based on the chemical qualities of the shallow alluvial groundwater versus the deeper Permian groundwater, it is considered unlikely that the two are hydraulically connected, or if so, only minimally (UCRA, June 2000). The alluvial deposits situated in the North Concho River Watershed are contiguous with and a continuation of the deposits of the Leona Formation, which is the alluvial component of the Lipan Aquifer. Although it has been reported that the Leona alluvial deposits and Permian deposits of the Lipan Aquifer are hydraulically connected, this hydraulic connection is not primarily geological, but rather man-made and due to the vast numbers of water wells that have been open hole completed in both units. Historically, prior to this mechanically induced hydraulic connection between the two units of the Lipan Aquifer, the shallow alluvial groundwater maintained much different chemical characteristics from the deeper Permian groundwater (UCRA, June 2000). In some areas of the Lipan Aquifer, where deeper drilling has not been prevalent, the groundwater in the Leona retains its antecedent chemical characteristics.

In the study area, the alluvial deposits consist predominantly of gravels, sand, clay, and conglomerates. The underlying Antlers Sand consists of mostly fine to coarse grained quartz sand, sandstone, and siltstone with a basal conglomerate of quartz, black chert, and clay pebbles, with interbeds of coarse sand. Its thickness in this area is reported as ninety to one hundred feet (90-100') (Bureau of Economic Geology, 1976).

The wells used in this study were drilled by oil companies searching for a water supply for exploration drilling purposes and no driller's logs are available. However, based on the elevation of the Antlers Sand outcrops and the location of Permian aged outcrops, it is considered likely that the Antlers is either absent by truncation or only a few feet thick in the study area. The underlying Permian strata consist predominantly of shale, sand, siltstone, and sandstone with minor interbedded gypsum and dolomite (Bureau of Economic Geology, 1976).

The head of Chalk Creek is incised into Cretaceous Limestones of the Edwards Group, which outcrop north of the study area. The Cretaceous Antlers Sand is exposed in the upper portions of Chalk Creek and undoubtedly underlies alluvial deposits in portions of the erosional valley. It is likely absent by truncation in the lower reaches of Chalk Creek. The precise location of the erosional pinch out of the Antlers Sand is uncertain.

Well Locations and Land Use Descriptions

In the feasibility study conducted prior to implementation of the North Concho River Watershed Pilot Brush Control Project, the overall size of the Chalk Creek sub-watershed was listed at 30,000+ acres, of which approximately 18,000 acres was covered with brush. Of that amount, 10,000+ acres was classified as heavy brush consisting of a mixture of brush species, but mostly mesquite, with an average canopy of greater than twenty-five percent (25%); 5,000+ acres was classified as heavy cedar consisting of mostly pure stands of juniper with average canopy cover greater than twenty-five percent (25%); and 2,500+ acres was classified as moderate brush consisting of a mixture of brush

species, but mostly mesquite, with a canopy cover of ten to twenty-five percent (10-25%) (UCRA, 2000).

The two wells, in which transducers were installed (Demere#1 and Demere #2), are located on opposite sides of Chalk Creek in an area where significant mechanical treatment has been implemented and no known groundwater withdrawal points that might affect the results exist. The well designated as Demere#1 is located approximately three hundred fifty (350') west of the centerline of the creek channel at N31˚39.1370' and W100˚41.3186'. It is situated approximately fifty feet (50') from one of the brush strips left in-place for wildlife habitat. The depth to groundwater in this well has been measured quarterly since the first quarter of 2002. Measured depths have varied from a minimum of 44.47' to a maximum of 48.61'.

The well designated Demere#2 is located approximately one hundred feet (100') east of the centerline of the creek channel at N31˚39.5654' and W100˚40.8679'. It is situated at the edge of the east-side of a brush strip that the owner left in-place along both sides of the creek's path. The depth to groundwater in this well has been monitored quarterly since the first quarter of 2002. Measured depths have varied from a minimum of 43.07' to a maximum of 45.99'. Geologically, both of these wells were drilled on the North Concho River's alluvial plain and into alluvial deposits that constitute the aquifer from which they produce.

Maps illustrating the relative position of the Chalk Creek sub-watershed within the North Concho River watershed and the position of the two utilized wells within the sub-watershed are included herein. The Chalk Creek sub-watershed is located adjacent to the westernmost boundary of the Lipan Aquifer (Bureau of Economic Geology, 1976) (Ashworth and Hopkins, 1995). Figure 1 illustrates the position of the Chalk Creek sub-watershed relative to the North Concho Watershed and Figure 2 illustrates the location of the wells within the sub-watershed. No other wells that could have contributed to the observed groundwater fluctuations were identified or are known to exist in the study area.

The ranch on which these wells are located consists of 3,742 acres, of which approximately 2700 acres have received mechanical treatment. A total of over seventy-two percent (>72%) of the mesquite has been removed from this property. Other landowners in this sub-basin have participated in the brush control pilot program to varying degrees. However, there remains a large percentage of the Chalk Creek sub-basin that has not been treated.

MEASUREMENTS AND ANALYTICAL METHODS

Study Design and Methods

The Demere#1well was equipped with a Solinst Levelogger Model 3001, LTC F100/M30, Serial Number 06382. The Demere#2 well was equipped with an identical logger, Serial Number 29662. Because the wells are proximally located, the use of a barologger was not deemed necessary as only measurements of relative elevation changes were sought.

The loggers were programmed to collect data in fifteen minute (15") intervals throughout the project period. They were installed in the wells and the collection of measurements was initiated on 06/22/04. Data was downloaded on 10/12/04 and the loggers were re-installed on the same day. Retrieval of the final data set occurred on 12/17/04, at which time the data collection phase ceased and the loggers were permanently removed from the wells. Due to equipment malfunctions, the data could not be successfully retrieved from either of the loggers. Solinst personnel in Canada were contacted by phone and after unsuccessful attempts to download the data during phone consultations, both dataloggers were ultimately sent to Solinst's offices in Canada for them to attempt to retrieve the data. They were able to successfully retrieve the data from the Demere#1 logger but could not retrieve the data from the other logger. It was shipped to the manufacturer in the Netherlands, but their efforts to retrieve the data also proved unsuccessful.

The time correlative precipitation estimates used in this study were obtained on-line from the Arkansas-Red Basin River Forecast Center (ABRFC) of the National Weather Service (NWS, 2005). They use sophisticated software to analyze Weather Surveillance Doppler Radar (WSR-88D) and observed precipitation data to create meticulously quality-controlled gridded precipitation estimates. These data are considered the most detailed, highest-quality spatial climate data sets currently available (NWS, 2000).

The initial design called for a much more rigorous data analysis than was ultimately possible, given the constraints imposed on the study from the aforementioned circumstances. However, even though only one “complete set” of data was available for analysis, several interesting and useful observations were made possible by fortuitous precipitation events that occurred during the data collection phase.

The levelogger data files from the Demere#1 well were converted to EXCEL spreadsheets. From the 17,000+ fifteen minute (15") discrete measurements, average hourly and average daily values were calculated. Correlative daily precipitation estimates from the study area were also entered into an EXCEL spreadsheet. These data sets were graphed for comparative analyses and are included in Figure 3 herein.

RESULTS, OBSERVATIONS AND CONCLUSIONS

Precipitation and Groundwater Elevation Curve Analysis

The groundwater elevation data set and the precipitation estimate data set were plotted against time. A comparative data analysis reveals that several rainfall events and one substantial groundwater elevation change occurred during the study period (see Figure 3).

From the beginning of the study period until approximately the middle of October, with the exception of minor positive and negative fluctuations, the groundwater elevation curve is generally in a slow, steady decline. The three short duration, low volume precipitation events occurring in June, July, and August were not accompanied by any discernable changes to the gradually declining groundwater elevation curve.

However, precipitation events occurring around the first part of October, the first part of November and, in particular, the event occurring from November 14 through November 17th were accompanied by discernable changes in the groundwater elevation curve. The events of early October and early November resulted in rapid, relatively minor upturns of the groundwater elevation curve of approximately two tenths of a foot (0.2') and three tenths of a foot (0.3') respectively.

Immediately after the early October rapid rise of approximately two tenths of a foot (.2'), the groundwater elevation curve resumed its slow, steady decline. However, on October 18th without the benefit of additional rainfall, the curve flattened, then reversed and began a very slow incline. Obviously, from the available data, the precise hydrologic mechanism(s) that caused this reversal cannot be definitively identified. A reduction in groundwater use by deep rooted mesquites due to the approach of winter with the concomitant decline in optimal growing conditions, the occurrence of on-going active recharge, or a combination of both likely explain the observed shift in the curve from a negative to a positive direction.

Immediately after the early November rapid rise of approximately three tenths of a foot (.3'), the groundwater curve resumed the slow steady incline initiated on October 18th. Again, the observed rising groundwater level was likely the result of either a reduction in groundwater use by deep rooted mesquites, the occurrence of active recharge, or a combination of both.

These small rapid upturns, in each case, followed several days of light rainfall, (average less than one/half inch (½") per day. However, during the heavier rainfall event that occurred in the middle of November, a pronounced, abrupt increase in the groundwater elevation occurred. The groundwater elevation rose by over one and one half foot (1.5') in two (2) days and almost three feet (3') over a one (1) week period. The total rise in the groundwater elevation measured from mid-November until December 17th was almost four feet (4'), and was still rising when the transducer was removed from the well at the study's termination.

This type of response to rainfall is not unprecedented. The Demere#1 is one of the wells in which the UCRA monitors groundwater elevations as part of the groundwater/surface water monitoring program for the Texas State Soil and Water Conservation Board's North Concho River Pilot Brush Control Project. Normally, the well is monitored quarterly. However, from July 3rd through July 7th 2002, an estimated three to four inches (3-4") of rain fell on the study area (UCRA, 2002) and additional groundwater level measurements were planned. The Demere#1 well was measured on June 24th, which was the regularly scheduled quarterly monitoring event. Due to the fortuitous timing of the rainfall event (shortly after the quarterly monitoring event), the well was subsequently measured on July 9th and again on July 19th to determine the response of the alluvial aquifer's groundwater elevation to the rainfall event. From the quarterly monitoring event measurement on June 24th to the July 9th measurement, the groundwater elevation in the well had risen one and six tenths feet (1.6'). From July 9th through July 19th the groundwater elevation rose another one and twelve one hundredths feet (1.12'), a total of two and seventy-two one hundredths feet (2.72').

From these observations, it is certain that the groundwater elevation in the alluvial aquifer exhibits a rapid response to significant rainfall events. However, by what process this rapid recharge occurs

and the quantity of recharge water necessary to produce the observed results is uncertain. Because the aquifer's hydraulic properties are unknown, the quantity of recharge required to produce the observed groundwater elevation changes cannot be precisely estimated. However, it is considered doubtful that the oil company that drilled the well would have set casing on a well that did not have enough groundwater in storage and a specific capacity sufficient to serve their needs, which would have been substantial. It is therefore considered likely that the storage coefficient of the aquifer in which the Demere #1 well is completed is relatively high, which is not uncommon in alluvial aquifers, and that a significant quantity of recharge water would be required to raise the groundwater levels by the amounts exhibited.

To what process can the recharge be attributed? Is the recharge due to channel transmission losses into the alluvial aquifer, groundwater from the limestone hills moving down gradient into the alluvial aquifer, from percolation of precipitation through the soils into permeable alluvial material, or a combination of two or all three of these mechanisms? The relative potential for each of these recharge processes to have contributed to the observed groundwater elevation changes in the Demere#1 well is briefly discussed below.

Aquifer Recharge Processes to Explain Observed Recharge Rates

Channel Transmission Loss as a Recharge Process

The UCRA has a USGS full range flow station installed on Chalk Creek downstream of the area of the well on Hwy 277. The records from that station during the mid-November rainfall event were checked to estimate the amount of runoff that could have contributed to the observed recharge through channel transmission losses. No runoff was recorded at this station during the time period of interest. It was determined that the USGS station was malfunctioning, and in the absence of flow data from the USGS station, a precise quantitative estimate of runoff that was generated by this sub-watershed could not be developed. It was determined however, that a small amount of runoff had occurred, approximately a one to two foot (1' to 2') rise that lasted only a few hours at most. This is known from visual observations conducted twice each day during the November rainfall/runoff

event. On only one (1) occasion, during the four (4) day period, was running water observed in the creek channel. The peak flow depth was determined from debris on brush in the creek channel and high water marks on the banks. Based on these observations, this relatively minor runoff event was evidently characterized by a short duration and shallow depth.

Because of exposed permeable alluvial material in the creek channel, it is considered likely that recharge from channel transmission losses was a contributor, although not likely the principal recharge source. Moreover, given the rapidity of the rise in groundwater elevation, the well's distance from the creek bed (greater than three hundred fifty feet (>350')), is another factor that militates against channel transmission loss as the predominant recharge process in this instance.

Groundwater Moving Down Gradient as a Recharge Process

The Demere#1 well is located in the lower reaches of the Chalk Creek sub-watershed, several miles from the limestone hills that divide the North Concho River and Colorado River watersheds. Using any reasonable value for transmissivity to calculate groundwater movement rates produces a result that negates this process as a significant recharge contributor to the observed rapid groundwater elevation response.

Percolation Into the Alluvial Aquifer as a Recharge Process

The negation of the preeminence of the two previously discussed possible recharge processes leaves percolation of rainfall into shallow alluvial material as the most plausible, likely predominant process to explain the observed recharge to the alluvial aquifer. Morever, the infiltration of precipitation over a large surface area is the most plausible recharge process that could yield enough water to the aquifer to raise the groundwater elevation as rapidly and as much as was observed in the Demere#1 well. In support of this supposition is the fact that, as previously mentioned, comparable rises in the groundwater elevation have consistently been observed in response to rainfall events (with limited runoff in some cases) during the groundwater/surface water monitoring program being conducted by the UCRA for the Texas State Soil and Water Conservation Board's North Concho River Pilot Brush Control Project.

Geologic assessments of the alluvial materials exposed in numerous cut banks of many of the ephemeral tributaries to the North Concho River indicate that they are typically comprised mostly of poorly sorted, permeable gravels located at very shallow depths, usually directly beneath the soils. It is considered more likely that the rainfall moved vertically through the soils into the alluvial gravels and then percolated rapidly through the permeable alluvial material down to a depth of forty-five feet (45'), rather than three hundred fifty feet (350') laterally from the creek bed in the short time frame available prior to the groundwater response.

Conclusions and Observations Regarding Recharge Processes

Since 2001, the quarterly monitoring results from wells spatially located throughout the watershed have consistently exhibited groundwater elevation increases in response to basin-wide rainfall events, which indicates a significant amount of recharge into alluvial aquifers. This recharge phenomenon has been observed in wells located near the North Concho River, on the alluvial plains, and on the uplands, which indicates that rapid recharge occurs essentially over the entire watershed.

Results from the continuous groundwater elevation measurements obtained for this study also exhibited a rapid rise in alluvial aquifer levels in response to significant rainfall events with limited runoff. The rapid rise in groundwater elevations observed in this study is mostly attributed to percolation of rainfall directly through the soil into shallow alluvial material then rapidly down to the water table.

Obviously, the precise relative contribution of each recharge process mentioned above cannot be unequivocally delineated from the Demere#1 well data. However, based on the reasoning presented above, it is considered likely that direct infiltration and percolation of rainfall is not only plausible, but in fact, is a substantive recharge mechanism. It is also considered likely that channel transmission losses contribute significant groundwater recharge when antecedent conditions and storm intensity/duration characteristics favor the production of significant runoff. Also, from direct visual observations, it is certain that rainfall that enters the porous limestones exposed in the hills

supports not only intermittent surface stream flows in the headers, but also recharges and helps to sustain groundwater levels in the alluvial aquifers as it moves laterally down gradient toward the river.

Observed Diurnal Pattern Evaluation

In addition to the rapid recharge that was measured, numerous graphs using the fifteen minute (15") time interval measurements and the hourly calculated averages revealed a distinct diurnal pattern in the data. This pattern is present in virtually all of the data graphs from summer and fall months. From a review of the graphs, two typical data signatures are evident; a decrease in the groundwater elevation from approximately 10:00AM or 12:00 noon until late afternoon and then an increase in the groundwater elevation from that point until approximately 10:00 AM to 12:00 noon the next day. This data signature was evident in virtually all time periods reviewed. This diurnal pattern is consistent with what would be expected from time-varying rates of consumption by plants whose roots penetrate to the water table. At a hydrostatic groundwater elevation in excess of forty feet (40'), the only plant species in this area that is known to have roots that can reach to this depth is mesquite. Although these data indicate a cause and effect relationship, measurements from one well, over an approximate six month period, does not necessarily provide conclusive evidence of a diurnal fluctuation that was induced by consumptive use of groundwater by deep rooted mesquites. Another possible contributor to the diurnal pattern is earth tides. Even though the alluvial aquifer is unconfined, which may diminish their effect, earth tides can cause regular cyclic groundwater fluctuations (Rojstaczer and Riley, 1990), which could be similar in intensity to those measured in the Demere#1 well.

In an effort to better understand the cause of the observed diurnal pattern, graphs constructed from data measured during the summer months (the growing season) and graphs constructed from data measured after the first hard freeze (after the cessation of evapotranspiration) were compared. Complicating this comparative analysis is the fact that the end of the growing season happened to coincide with the significant recharge measured in the Demere#1 well. An aquifer undergoing

sufficient recharge can overwhelm the diurnal pattern whether that pattern is produced from earth tides or from consumptive vegetative use.

In an effort to lessen this potential, the “flattest” portion of the post-freeze data set, i.e. that portion of the data set which was least influenced by active recharge, was chosen for comparative analysis. Although recharge was still occurring, it was to a lesser extent during this time period than in other time periods when the groundwater level was rising at a more robust pace. The chosen data set was graphed and paired with a graph of a comparable time interval from the summer growing season. The post-freeze data consisted of the measured data set from the week of 12/05 -12/12 and the summer data consisted of the measured data set from the week of 8/1-8/8. The August dates were chosen because, for a significant time period before and during this week, there was negligible rainfall. The graph constructed for comparison purposes is presented herein as Figure 4.

To present the data on a scale that provided an optimal view it was necessary to add three feet (3') to each of the measurements included in the August data set. This moved the line graphs close enough together to allow a better comparison of the two.

The graph from the summer growing season illustrates the typical diurnal pattern previously described, i.e. groundwater elevation remaining stable or rising from late afternoon through the night until approximately late morning or noon then sharply down until late afternoon. If the graph from a post-freeze data set exhibits a diurnal pattern of equal intensity, then the diurnal pattern can most likely be attributed to earth tides. Conversely, if the opposite is true, then it would indicate that consumptive use by mesquite (in this case) may be significantly contributing to the observed phenomenon.

On most days, the graph from the post-freeze time period illustrates a downturn in the measured levels beginning about noon and continuing until late afternoon, which indicates an influence from earth tides. However, the downturn is subdued compared to the measurements from August. This diminished decline in the downward movement of the groundwater elevation is not unexpected.

Since the aquifer is receiving recharge, it is entirely plausible that the rate of decline caused by earth tides would be offset by the rate of recharge, resulting in a damped response. By itself, this data would seem to indicate a causal relationship to earth tides alone.

However, when the time period between midnight (labeled "24" on the graph) until noon is examined, it can be seen that, in the post-freeze period, on six of eight occasions the water level is declining. Arrows have been placed on the graph to illustrate the direction of groundwater flux during these daily time periods. This is opposite of the expected result if earth tides were solely responsible for the diurnal fluctuation. If earth tides were the sole cause for the diurnal flux, the time period before midnight through morning should exhibit a strong rise in groundwater levels since both earth tides and recharge would be influencing the groundwater flux in the same direction at the same time. What was measured and displayed on the post-freeze graph is the opposite.

Although the data and observations from this one well are not considered conclusive evidence to demonstrate a definite causal relationship from deep rooted mesquites directly accessing groundwater and contributing to the observed diurnal cycle, an unquantified probability that this is the case has been established. Further research and field experimentation is needed to determine the degree to which mesquites, through consumptive use of groundwater by their deep roots, can affect groundwater level fluctuations in unconfined aquifers.

FINAL COMMENTS

Despite the fact that the alluvial aquifers of the North Concho River watershed are overlain, sometimes by deep soils with calcic horizons and indurated caliche layers, the results of this study indicate that rapid, direct percolation of rainfall through the soil horizon into the shallow alluvial aquifers of the North Concho River watershed does occur. Analysis of the data from this study combined with the tentative results of the groundwater/surface water monitoring program being conducted by the UCRA for the Texas State Soil and Water Conservation Board's North Concho River Pilot Brush Control Project verify that not only does direct percolation occur, but it is a significant recharge process for the alluvial aquifers of the North Concho River.

This finding is directly contradictory to the viewpoints of others who have proffered the opinion that, in rangeland areas where soils are deep and the presence of a calcic horizon exists, little if any water moves beyond the (grass) root zone (Wilcox, 2002). Those who hold this viewpoint consider publically funded brush control programs that target mesquite infestations on uplands to be an unwise use of public funds. The basic tenant of this viewpoint is that in semiarid and subhumid landscapes, i.e. a soil-water-deficient system, evaporation potential exceeds annual precipitation, and regardless of the vegetative cover, almost all rainfall that does not runoff will be either evaporated or used by whatever vegetation is present (Wilcox, 2002). The upshot of this thinking, regarding the control of mesquite infestations, is the premise that if mesquite is treated, herbaceous vegetation will take its place and use all of the water that would have been used by the mesquite.

What this viewpoint fails to recognize and what this study conclusively demonstrates, is that rainfall does rapidly move into and recharge alluvial aquifers, even in areas with deep soils and calcic layers. This is true for the North Concho River watershed, and undoubtedly in other cases where favorable hydrogeologic characteristics exist. This rapid recharge most likely occurs as both direct percolation and channel transmission losses, with the antecedent watershed conditions and storm intensity/duration characteristics being the factors that determine which is most prevalent in any particular rainfall event.

Once stored in alluvial aquifers, the groundwater is available and used by the deep rooted mesquites. This is evidenced by the diurnal patterns observed in the data collected for this study. This finding supports the premise that in situations where mesquites utilize groundwater located below grass root zones, the control of mesquite would increase streamflows.

The key to whether a watershed system functions more according to the viewpoint of Wilcox and others or according to the findings of this study is dependant on the watershed's specific hydrogeologic characteristics. Although the geologic issue is mentioned as one of the controlling factors of how streamflow in drylands responds to changing vegetative cover (Wilcox, 2002), differences in hydrogeology apparently are not, in reality, given due consideration by those making broad statements repudiating the efficacy of mesquite control as a streamflow enhancement strategy.

Obviously, the observations of this study are not definitive and the research is certainly not exhaustive. Much additional research is needed, especially on a watershed scale. The aggregate results from existing empirical scientific studies are inconclusive regarding the relative merits of favoring one particular ecoregion or brush species over others, as some have done. It is abundantly clear that a particular watershed's hydrologic response to brush control is uniquely linked to its intrinsic geology, soil, flora, and topography, and the complex interactions among each of these factors with climatic influences.

The one unquestionable conclusion that can be drawn from the existing body of research is that the evaluation of a watershed's potential hydrologic response from brush control should be conducted on a watershed scale and based on careful consideration of all the intrinsic properties of a particular watershed, rather than on generalizations.

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FIGURES

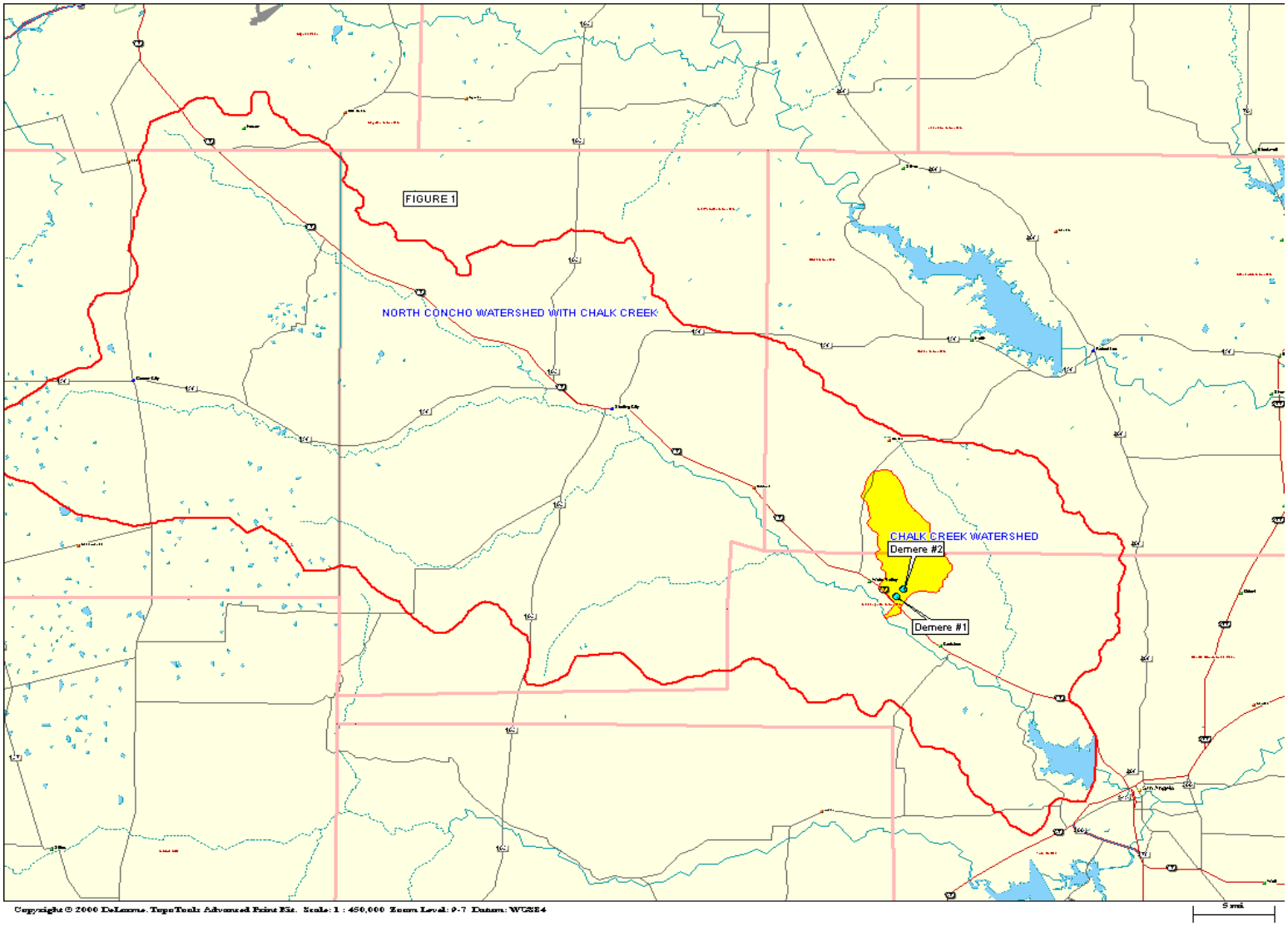

Figure 1

North Concho River Watershed with Chalk Creek Sub-Watershed Highlighted

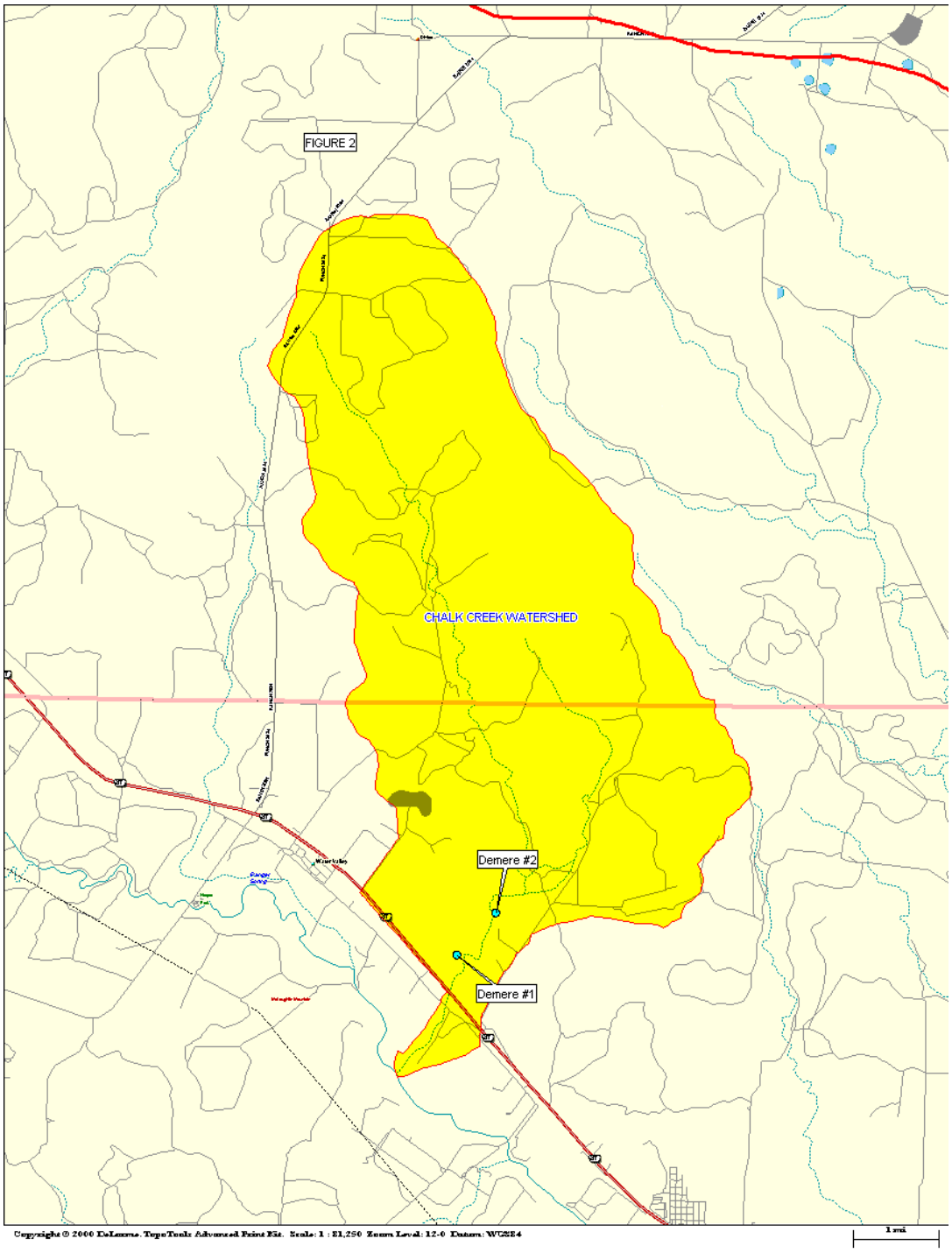

Figure 2
Chalk Creek Sub-Watershed

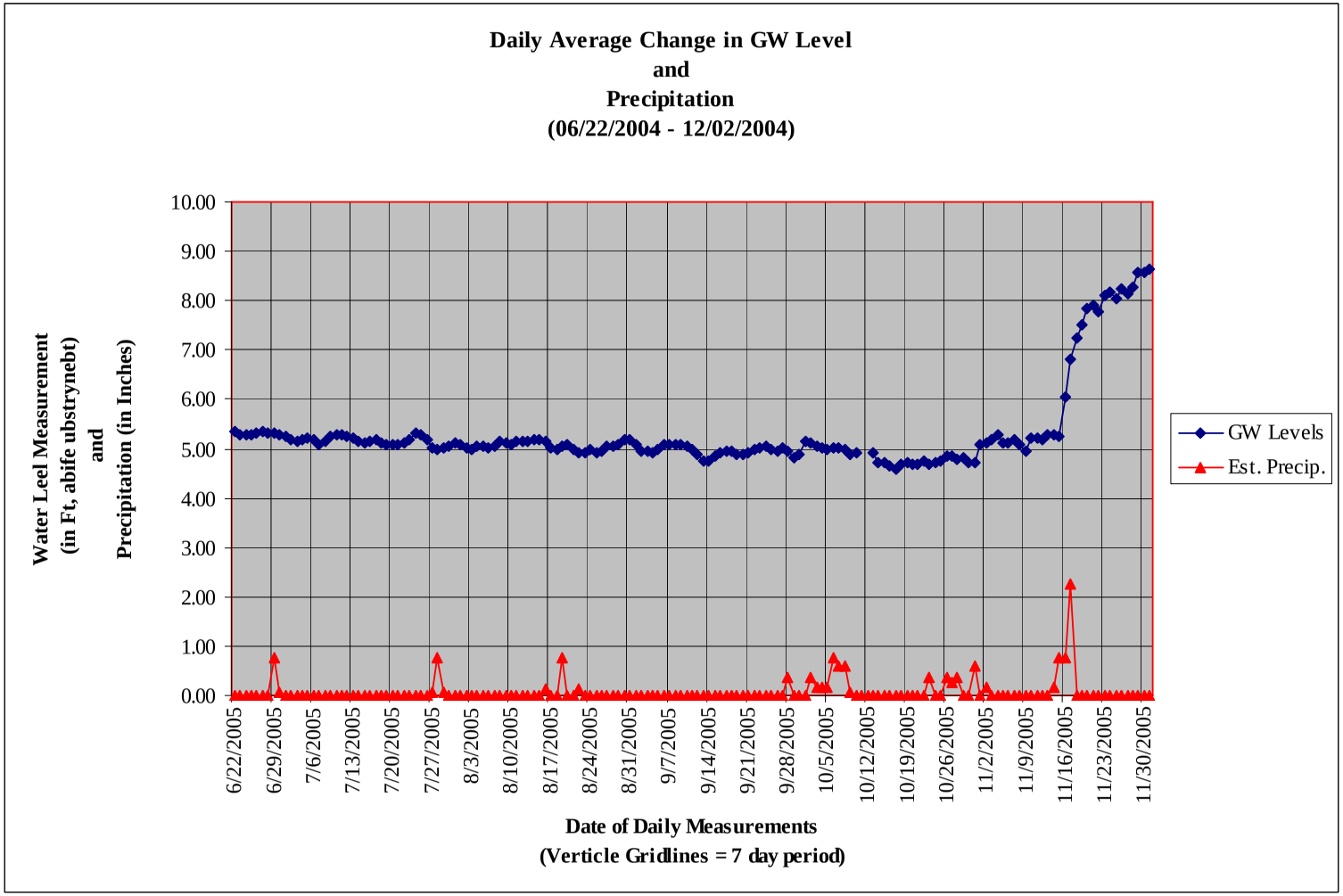

Figure 3
Daily Average Groundwater Elevation and Estimated Precipitation

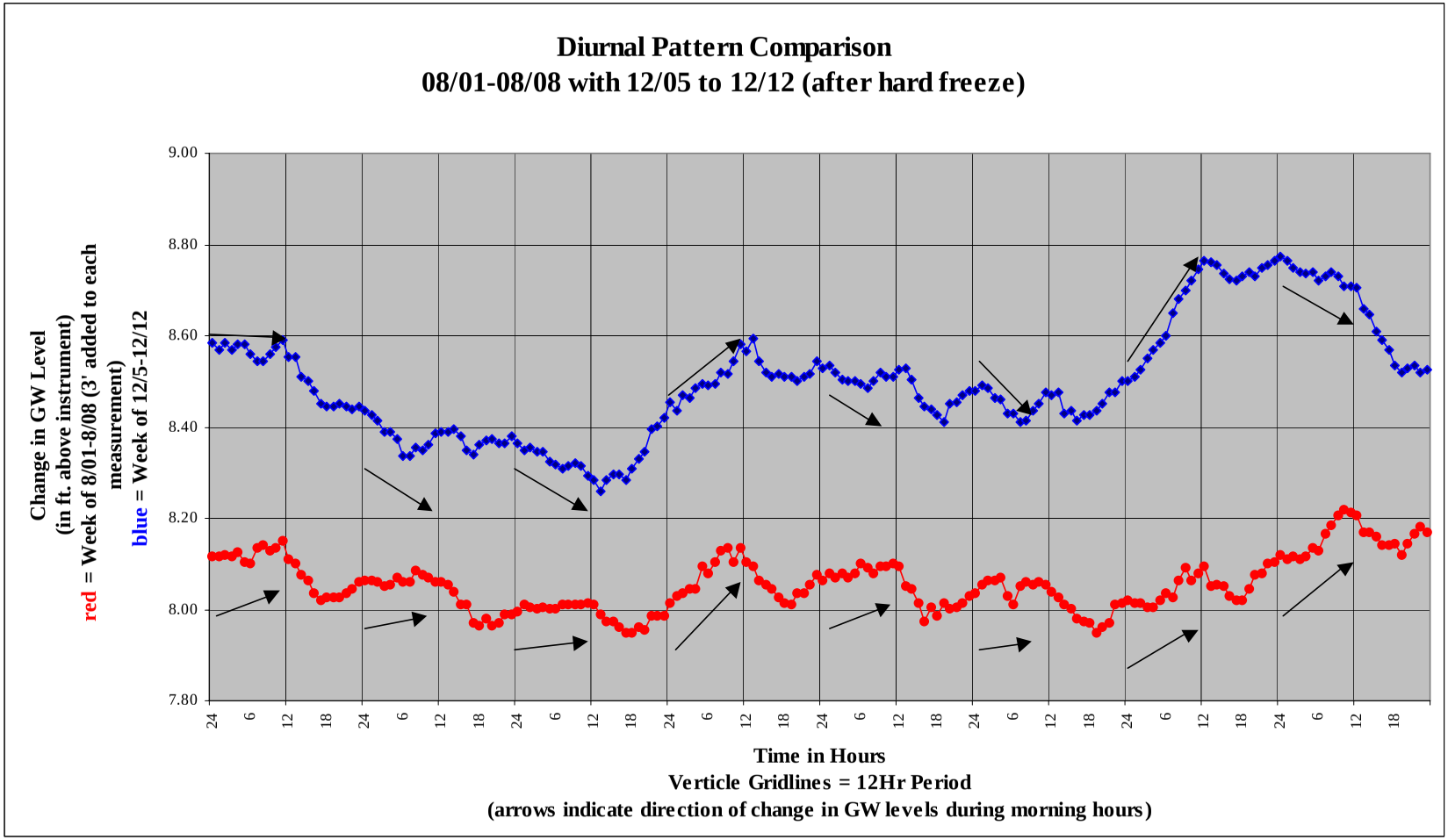

Figure 4
Diurnal Comparison Chart

EXECUTIVE ADMINISTRATOR’S COMMENTS